Better Crops

WITH PLANT FOOD

May-June 1962

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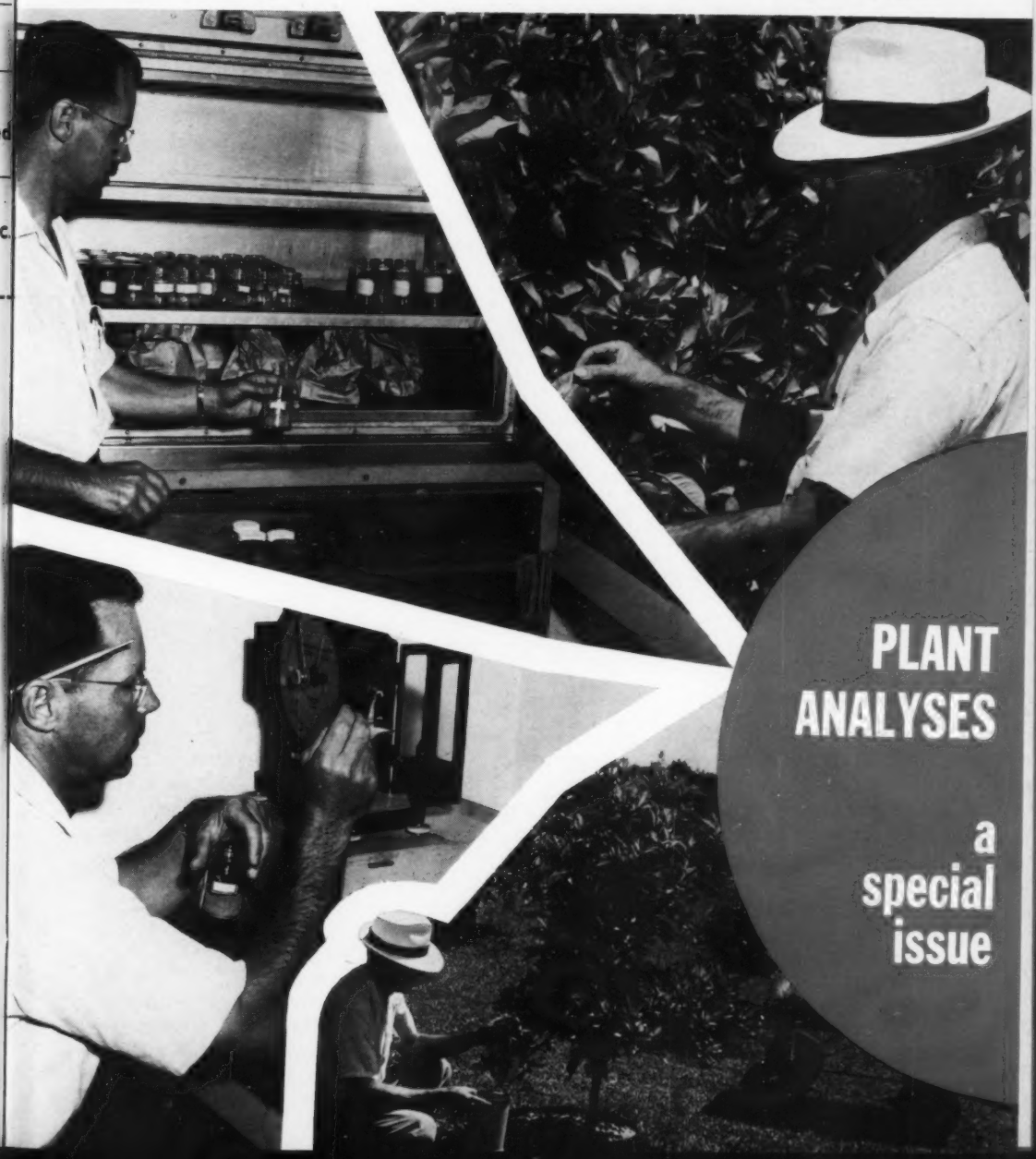

PLANT ANALYSES

a special issue

Better Crops
WITH PLANT FOOD

The Whole Truth—Not Selected Truth
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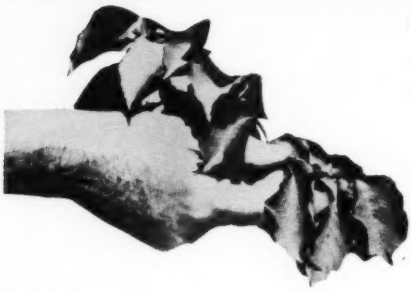


Cover format developed from pictures provided by USDA—showing leaf analysis work on oranges at the U. S. Horticulture Field Laboratory, Orlando, Fla.

. . . FROM LEAF TO YIELD

TODAY the successful farmer cannot depend on guesswork as a guide to fertilizer application. He cannot afford to. Farming has become a precision business demanding reliable knowledge of plant nutrition needs.

Plant analysis—like soil testing—has become an acceptable research and educational tool in helping the farmer answer questions basic to his economic future: Should I fertilize? What analysis? How much? How often?

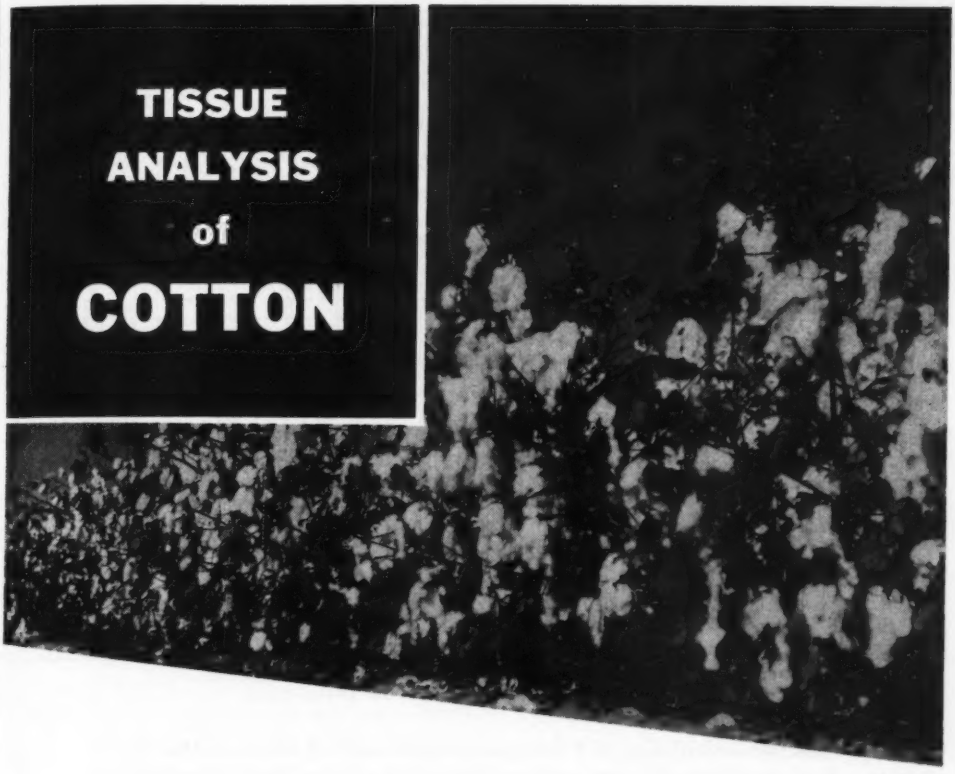
For these reasons, the American Potash Institute has invited some of the nation's top authorities on plant analysis to discuss the progress in this field of agricultural research.

Plant analysis is a relatively rapid way of diagnosing the nutritional needs of a crop by using the plant itself as an indicator.

Many questions and problems are involved, of course. Perhaps three basic ones are: (1) Which part of the plant to sample, (2) which test to use in chemically analyzing these samples, (3) what nutrient concentration to label "adequate" for specific plant growth. These and other problems are discussed in this issue.

Special Issue Chairman is Dr. R. P. Humbert, Institute Western Director.

TISSUE ANALYSIS of COTTON



PROBLEMS in cotton tissue testing resemble those of other crops: Plant part to be sampled, stage of growth for sampling, and the type of test to use. And, of course, correct interpretation of the test results is vital.

Plant Part to Sample

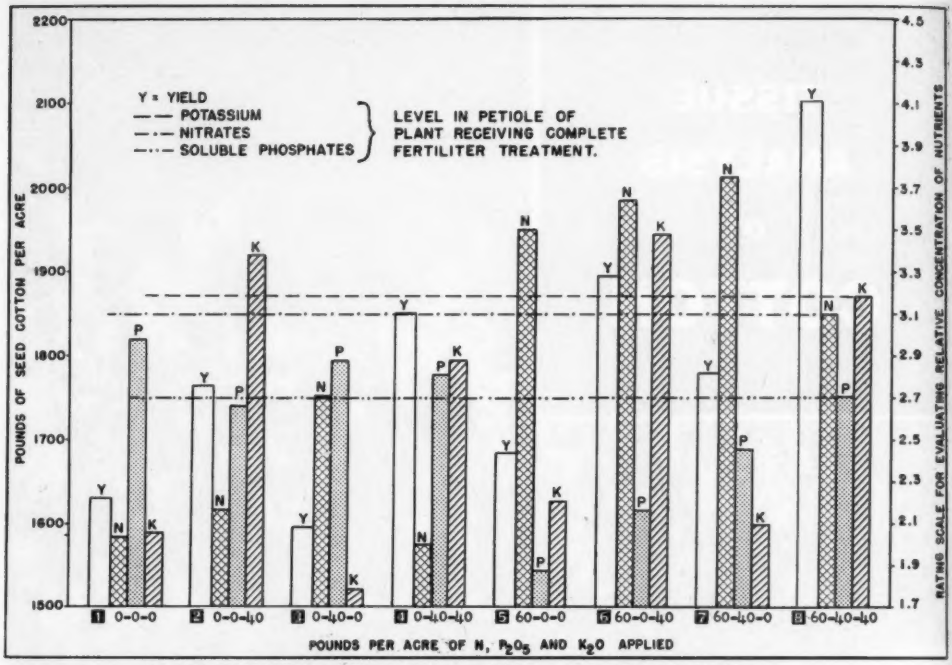
At present the petiole from the most recently developed full size cotton leaf is being used for analyses by many workers. Joham of the Texas Agricultural Experiment Station suggested in 1951 that petioles be taken from the main stem at the third or fourth node from the apex—the position where the most recently developed full size leaf is usually found. This upper petiole is being used by Tucker in Arizona for nitrogen studies, also by Bassett and McKenzie in California, and by Masters, Harvey, Wendt and Walker in Texas. Stromberg and Fullmer have also reported work in California using the upper petiole.

The literature on petiole analysis of cotton should soon increase since most of the above named workers have publications in preparation at this time.

In Arkansas work, we have found

By
Glenn W. Hardy

Arkansas
Agricultural
Experiment Station



EFFECT OF VARYING LEVELS OF N, P AND K ON THEIR RELATIVE CONCENTRATIONS IN COTTON PETIOLES AND ON TOTAL YIELD.

Figure 1—This test—consisting of 8 treatments replicated 12 times—shows some problems that can arise when interpreting tissue test results. Data recorded for each element in each treatment of each replication was the average result from testing 4 petioles. Two points stand out:

1 **Even when a plant shows desired (or above) concentration of a specific element in a given part on a certain sampling date, the element still may not be in adequate supply for high yields.**

For Example: Treatment 1 indicates that N and K are deficient since both are far below their level shown in treatment 8. By similar reasoning, P seems quite adequate in treatment 1. But note what happened when N deficiency was corrected in treatment 5—P was then deficient.

2 **The interaction of two elements can affect the concentration of another element in the petiole.**

For example: Adding K caused little change in nitrate concentration when P was not added (compare treatment 1 with 2 and 5 with 6)—But when K was added with P, the nitrate level was markedly reduced (compare treatments 3 with 4 and 7 with 8).

leaf blades early in the season equally as satisfactory as petioles for analysis. Samuels, Rodiquec, and Landrau, reporting through the University of Puerto Rico Journal of Agriculture, say leaf blades were especially desirable for early season sampling. Stems and fruit structures have been used by other workers. Leaf blades are satisfactory material when the tissue is to be dried and analyzed in the laboratory, but not as convenient to use as petioles in field testing procedures.

Time of Sampling

Time of sampling is important from two standpoints: (1) Detecting deficiencies in time to correct them, (2) interpreting what is learned from the test. The earlier nutrient deficiencies can be detected, the better opportunity for correcting them during that season.

The N, P, and K level of either cotton leaf blades or petioles will usually increase some during the early part of the season, but begin decreasing by heavy flowering time and continue to decrease through the rest of the season.

Since the nutrient level changes during the growing season, a satisfactory nutrient level for each element must be determined for each growth stage to be sampled. This can be done with carefully conducted and properly sampled field fertilizer experiments.

Type of Tests Used

The procedures most widely used by workers mentioned in this article are those described by Johnson and Ulrich in the *California Agricultural Experiment Station Bul. 766*. These laboratory procedures are used to determine water-soluble nitrogen and acid-soluble phosphates, with a dry ashing procedure used for potassium.

Essentially the same form of each of these elements can be determined in the field by quick testing methods.

Recent Arkansas work has found tissue tests in the field sufficiently sensitive to measure the response in petiole concentration of N, P and K to fertilizer applications of these elements.

The accompanying graph (Figure 1) illustrates the type of data that may be obtained with such tests. The rating scale, used for evaluating the relative concentration of the various nutrients, is best explained by briefly describing the tests used:

1 For Nitrates

Bray's test, as modified by Maples of the Arkansas Agricultural Experiment Station and Morgan of the American Potash Institute, was used for water-soluble nitrates. This test extracts nitrates from the crushed ends of petioles in 5 cc of water, then adds nitrate powder to the extract. In this case, the resulting color was compared to *six* standards established with known concentrations of sodium nitrate. These standards were assigned numerical values of 1 to 6, ranging from low to high concentration.

2 For Phosphorus

Phosphorus determinations were made by extracting the crushed ends of petioles in acidified ammonium molybdate solution. The color was developed with a tin rod. Comparisons were made with the colors on the Purdue color chart to which numerical values of 1 to 5 were assigned. *(Ind. Exp. Station Bul. 635).*

3 For Potassium

Potassium determinations were made by using dipicrylamine test papers. These papers consisted of three test dots of dipicrylamine of varying

concentrations. Plant sap was expressed from petioles onto each of the three dots. After one minute, the dots were washed with a weak hydrochloric acid solution. It was found the amount of yellow color left on the paper could be rated on a scale of 1 to 9. The dot which indicated low potassium was rated 1 to 3 depending on whether a trace, about 50%, or the complete dot remained after the acid wash. The medium level dot was rated 4 to 6, and the high level dot was rated 7 to 9.

Using a numerical rating scale gave two advantages over the conventional high, medium, low classification system:

1 Permitted statistical analysis of the data.

2 Increased sensitivity of the tests so smaller differences than usual could be recorded.

As Figure 1 shows, values for potassium ranged from 1.75 to 3.48—which would be classed medium or low under the usual system.

The test (shown in Figure 1) consisted of the eight treatments replicated 12 times. Datum recorded for each element in each treatment of each replication was *the average resulting from testing four petioles.*

Interpreting Test Results

Figure 1 shows some of the problems that arise in interpreting tissue test data.

One of the most important things to know when evaluating a test for a particular element is the level at which the element should be at a given sampling time. Even when a plant shows desired (or above) concentration of a specific element in a given part on a certain sampling date, the element still may not be in adequate supply for high yields. The graph illustrates this.

For discussion purposes, it was assumed the NPK levels in the complete fertilizer application (treatment 8) were at a desirable level. At least the levels were the best in this experiment, since this combination of nutrient concentrations produce more cotton than any other.

When examining the data in treatment one, we might conclude the N and K are deficient since both are below their level in treatment eight. By the same reasoning, we might consider P in adequate supply. But when the N deficiency was corrected, as in treatment five, the P level dropped and P was now deficient. Several other such examples may be worked out from the data in the graph.

When interpreting tissue test data, you can consider a specific element at a satisfactory level only if the other elements tested are adequate.

Certain other relationships became apparent when these data were studied. For example, adding K caused little change in nitrate concentration when P was not added (compare treatment 1 with 2 and 5 with 6). But when K was added with P, the nitrate level was markedly reduced (compare treatment 3 with 4 and 7 with 8). This interaction was found to be important at the .05 point of probability when the rating scale values were analyzed factorially. These data are shown here:

Effect of the Interaction of Phosphorus and Potassium on the Relative Nitrogen Concentration in the Petiole

K_2O lbs./A	P_2O_5 lbs./A	
	0	40
0	2.77 ab[1]	3.23 a
40	2.90 ab	2.55 b

[1] Values with one or more common letters belong to the same population as measured by Duncan's multiple range test at the .05 level of probability.

In Summary

Leaf blades and petioles are satisfactory indicators of the nutrient status of the cotton plant. The petiole from the most recently fully developed leaf is currently the most frequently used plant part for both laboratory and field procedures.

While the concentration of plant nutrients may show deficiencies to a greater extent late in the season, earlier sampling has been found useful after careful work has been done to establish desirable levels in the plant at a given growth stage.

Assigning numerical values to field tissue test results increases their sensitivity and permits the results to be submitted to statistical procedures.

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GRADE YOURSELF
(on cotton)

Most specialists tissue testing cotton take the petiole from the most recently developed full size cotton leaf, usually found on the main stem at the third or fourth node from the apex.

True ☐ False ☐

Some workers have found leaf blades early in the season equal to petioles for analysis, especially when the tissue is to be dried and analyzed in the lab.

True ☐ False ☐

Leaf blades are just as convenient as petioles for field testing procedures.

True ☐ False ☐

The NPK level of neither cotton leaf blades nor petioles will vary during a growing season.

True ☐ False ☐

Tissue tests in the field are sufficiently sensitive to measure the response in petiole concentration of NPK to fertilizer applications of these elements.

True ☐ False ☐

A specific element is in adequate supply (or level) when the tissue test says so, regardless of the other elements.

True ☐ False ☐

The interaction of two elements can affect the concentration of another element in the petiole.

True ☐ False ☐

FIGURE 1

When sampling potato plants, specialists use petioles of the fourth leaf below the growing tip of the plant—generally the youngest fully expanded leaf on the plant.

DIAGNOSING NUTRIENT NEEDS

By K. B. Tyler

and

O. A. Lorenz

MOST commercially grown vegetables are heavy yielding, rapidly maturing crops with high nutrient demands—generally produced on soils intensively cultivated and heavily irrigated and fertilized.

The importance of proper fertilizer management of vegetable crops produced under these conditions is being recognized more and more.

Plant analysis techniques, to determine the plant's nutrient status, are now becoming available for such crops as potatoes, lettuce, cabbage, celery, melons, sweet corn, and tomatoes.

In California, more experimental work has been done to establish the critical nutrient levels in potatoes than with any other single vegetable crop. For this reason, potatoes are used here to illustrate the use of plant analysis in determining nutrient requirements.

TABLE 1—A PLANT ANALYSIS GUIDE FOR SAMPLING TIME, PLANT PART, AND DEFICIENCY LEVELS ON 7 VEGETABLE CROPS

Crop	Time of Sampling	Plant Part	Deficiency levels		
			NO_3—N ppm	PO_4—P ppm	K per cent
Cabbage	At heading	Leaf midrib of wrapper leaf	5,000	2,500	2
Celery	At midgrowth when 12–15" tall	Petiole of youngest fully elongated leaf	5,000	2,000	4
Lettuce	At heading	Leaf midrib of wrapper leaf	4,000	2,000	2
Melons	Early fruitset	Petiole of 6th leaf from growing tip	5,000	1,500	3
Potatoes	Midseason 35–45 days from emergence	Petiole of 4th leaf from growing tip	6,000	800	7
Tomatoes	Early bloom	Petiole of 4th leaf from growing tip	2,000	1,500	1.5
Sweet corn	At tasseling	Leaf midrib of 1st leaf above primary ear	500	500	2

IN VEGETABLES

University of California

Procedures Used

Numerous field experiments and field surveys were conducted in cooperation with farm advisors and individual growers in the important potato producing districts of California. From these tests, soil and plant samples were taken and the analyses related to fertilizer application and to later yield of plants grown on differently fertilized plots.

To secure the most accurate results possible, we followed these basic steps:

1 Soil samples, taken from the surface foot in all fields prior to planting the crop, were analyzed in the laboratory for available phosphorus and potassium.

2 Plant sampling was initiated as soon as plants reached sufficient size to provide the necessary foliage for samples—usually 3 to 4 weeks after emergence—and was continued at approximately two-week intervals throughout the growing season.

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3 Individual samples consisted of 40 to 50 petiole sections of the fourth leaf below the growing tip of the plant, generally the youngest fully expanded leaf on the plant—as shown in Figure 1.

4 Analyses for nitrate-nitrogen and phosphate-phosphorus extractable in 2% acetic acid were made on the dried, ground petiole tissue.

5 An ashed sample was used for estimating total potassium, calcium, and magnesium.

6 Plant samples were analyzed by conventional methods as outlined by Johnson and Ulrich.

7 Available soil phosphorus was determined by the sodium bicarbonate method described by Olsen.

8 Exchangeable potassium was estimated by extracting 50 grams of soil with 500 ml. of normal neutral ammonium acetate.

In the field experiments, three or more rates each of nitrogen, phosphorus, and potassium were applied to adequately replicated plots. Plants grown on these plots provided the samples used for analysis.

Most experiments were with the White Rose variety but some were with Russet Burbank and Kennebec. All varieties seemed to respond similarly to fertilizer treatments.

Yield records taken at harvest were related to soil analyses, plant analyses, and fertilizer treatment. These records are presented in more detail in Calif. Ag. Exp. Sta. Bul. 781.

With the three major elements, the record showed this:

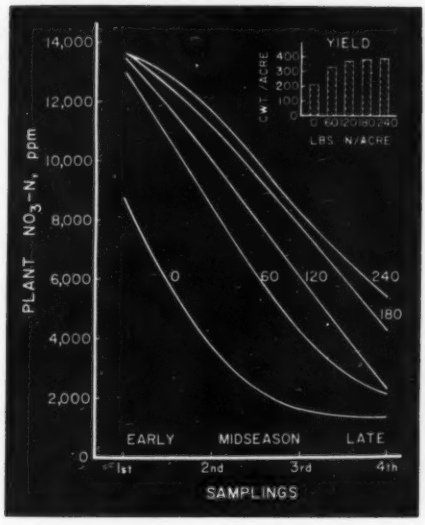


FIGURE 2

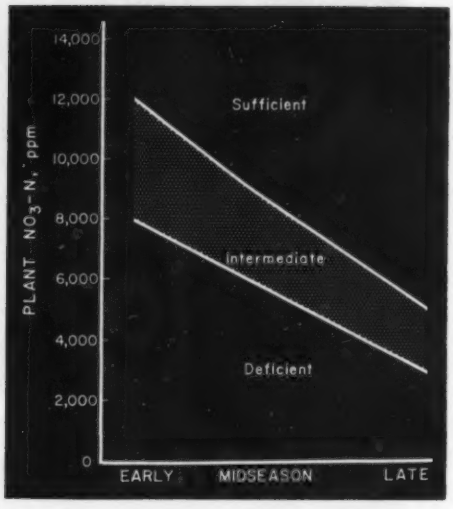


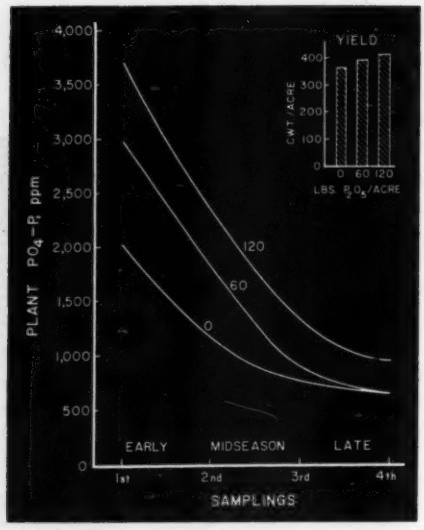
FIGURE 3

NITRATE

Under field conditions nitrate-nitrogen in plant petioles is generally high during early growth. It decreases rapidly with time and at maturity, practically regardless of the amount of nitrogen applied, it is usually present in relatively low concentration.

Figure 2 shows how this happens by averaging 15 field experiments conducted in Riverside and San Bernardino Counties from 1958 to 1960. At first sampling, the difference between nitrogen-fertilized and non-nitrogen fertilized plants was sharp, although all plants were high in nitrate regardless of nitrogen application rate. The nitrate level dropped rapidly as the plants matured. At late season, nitrate-nitrogen levels often fall to very low concentrations without corresponding reductions in yield. In fact, as long as the nitrate-nitrogen is at a safe level during *midseason growth*, it appears yields are not diminished. This has been observed in many field tests even when nitrate content has approached zero during late periods of growth.

Figure 3 shows an estimation of sufficient, intermediate, and deficient levels of nitrogen in relation to age of the potato plant. Plants with nitrogen concentrations in the sufficient range—above the upper curve—are well supplied with nitrogen, and as far as this nutrient is concerned, would produce high tuber yields. Plants with nitrogen concentrations in the intermediate range—between the two curves—might or might not respond to additional nitrogen fertilization, depending on other environmental factors. Values below the lower curve would be considered deficient and normally associated with decreased yields. Nitrate-nitrogen levels below 8,000 ppm during early growth, 6,000 at midseason, and 3,000 near maturity are considered to be deficient.



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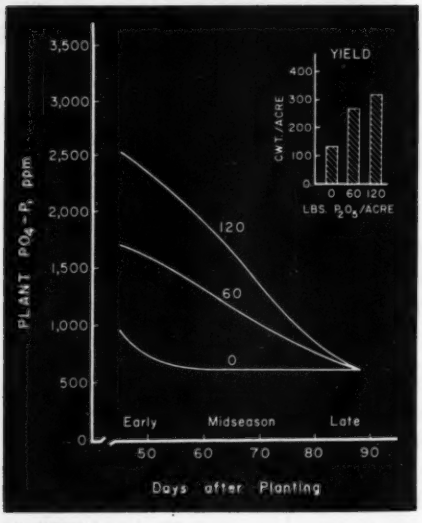


FIGURE 5

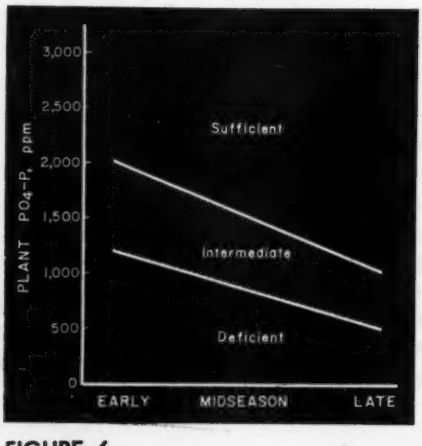


FIGURE 6

PHOSPHORUS

Phosphate-phosphorus in potato petioles is usually much lower in concentration than nitrate-nitrogen but during normal growth shows the same relative rate of decrease.

Figure 4 shows an average of analyses and yields from 21 field experiments in Kern, Riverside, and San Bernardino Counties. In early season, the difference in phosphate-phosphorus concentrations was sharp between phosphorus-fertilized and non-phosphorus plants. At the late season growth stage, these differences became much smaller and often approached the same level regardless of the phosphorus application rate. *This emphasizes the need of early sampling to determine the nutrient status and phosphorus needs of potato plants.*

Figure 5 shows how phosphorus concentration of potato plants changed in an experiment on a soil of low available phosphorus. Because of a very limited supply of available phosphorus (9 ppm PO_4-P), yields were unsatisfactory unless fertilizer phosphorus was applied for the crop. Phosphorus levels in the plants at early season varied markedly in relation to rate of phosphorus application. At the final sampling in late season, plants from all three phosphorus treatments were low and similar in phosphorus content. This again illustrates the necessity of early sampling, either during early or midseason growth, to evaluate phosphorus status of potatoes.

As with nitrogen, phosphorus concentrations in potatoes may decrease to very low levels at season's end—less than 500 ppm PO_4-P in many instances. This often occurred without affecting yield or quality, *if sufficient phosphorus had been available and was taken up by the plant during the early and midseason stages of growth.*

Phosphorus-deficient potato plants generally appear normal, healthy, well-nourished except when compared with normal plants receiving adequate phosphorus. Then they are found to be stunted or retarded in growth. Be-

cause phosphorus deficiency symptoms are difficult to identify by visual inspection in the field, plant analysis is important in verifying the phosphorus needs of potatoes.

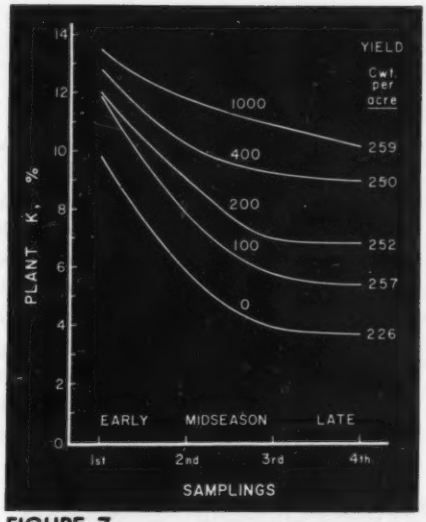
Figure 6 shows an estimation of sufficient, intermediate, and deficient levels of phosphorus in relation to age of plants. As with nitrogen, plants with phosphorus concentrations in the intermediate range—between the two curves—might or might not respond to additional phosphorus, depending on other environmental factors. Analyses below the lower curve would be considered deficient and would normally be increased by higher phosphorus fertilization and absorption. And analyses above the upper curves are sufficient enough that yields would not be increased by phosphorus fertilization or greater phosphorus absorption.

POTASSIUM

During very early growth, potassium concentrations in potato petioles are high even when grown on soils relatively low in this nutrient.

Figure 7 shows how potassium levels, resulting from differences in soil potassium availability, increase as the season advances—averaged from 8 Kern County experiments of 1958.

Figure 8 shows results from one of these fields that had very low exchangeable potassium content (46 ppm K). In early season when the first sampling was made, plants from all potassium treatments showed a relatively narrow range of potassium concentration. At midseason the difference between the unfertilized plants and those getting 400 lbs. K_2O was more than double the difference at early season, and this difference continued to increase for the rest of the season. This shows the need for sampling *no earlier than midseason* to determine the potassium status of potato plants. Until tuber growth begins, the differences in potassium content between potassium-deficient and potassium-sufficient plants remain



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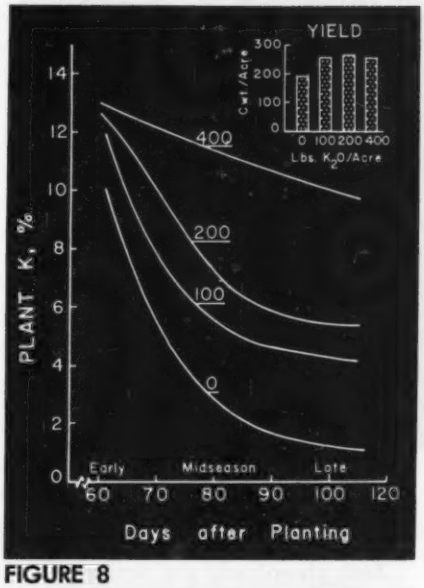


FIGURE 8

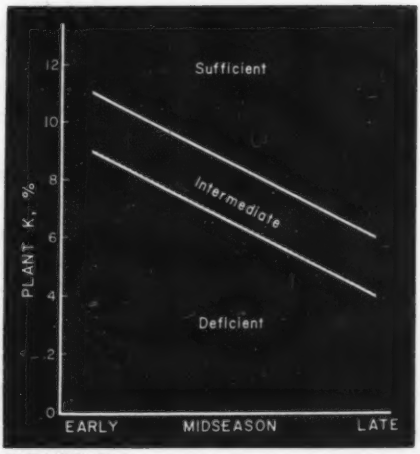


FIGURE 9

small, becoming greater as plants approach maturity. In these studies, potassium content of potato petioles in California was found as low as 0.2% at late season and as high as 16% in some midseason samples.

Figure 9 shows an estimation of sufficient, intermediate and deficient levels of potassium at various stages of growth.

Analyses above the shaded area indicate sufficient potassium while those in the shaded sector may or may not be deficient. Differences in the nitrogen and phosphorus composition of plants grown on deficient and adequately fertilized soils are greatest during *early growth* but may show almost no difference by maturity. But with potassium, maximum composition difference between adequately fertilized and deficient plants is found *at the later periods of sampling*.

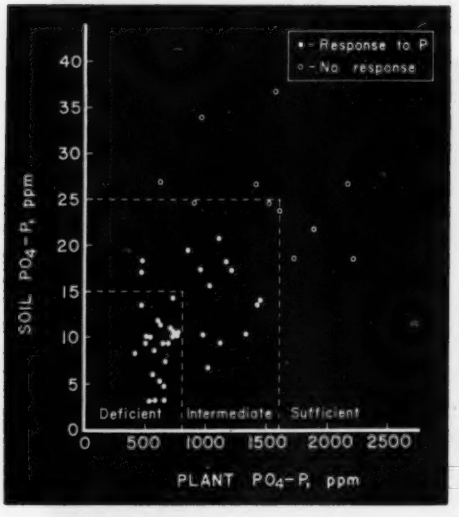


FIGURE 10

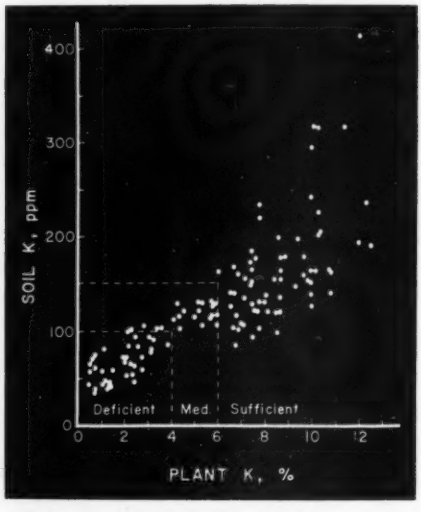


FIGURE 11

PLANT AND SOIL TESTS—CLOSE KIN

Both phosphorus and potassium soil tests for potatoes were also studied.

Figure 10 shows the soil phosphate-phosphorus plotted against the phosphate-phosphorus in the plant petioles at midseason. Levels of bicarbonate soluble phosphorus (P) as low as 5 ppm and as high as 50 ppm were analyzed in the potato-producing soils of California. Fields with less than 15 ppm soil phosphorus showed increased yields when phosphorus was applied. In the same fields, plant phosphorus concentrations were generally deficient—less than 800 ppm at midseason—without phosphorus application. In the range between 15 and 25 ppm soil phosphorus, some fields gave yield response to phosphorus application, but many did not. Above 25 ppm soil phosphorus, no yield responses to phosphorus fertilizers were recorded and plant phosphorus concentrations were adequate.

Exchangeable potassium in California potato soils varied widely, ranging from a low of 30 to a high of 400 ppm K. Most of the low potassium soils were

of lighter texture and had been in potato production for several years. *Many California soils that have been cropped frequently to potatoes are becoming depleted of available potassium.* Samples taken from areas of uncropped soil near older potato fields analyzed up to four times higher in exchangeable potassium than those from corresponding adjacent areas within the potato fields.

Figure 11 shows the exchangeable soil potassium plotted against plant petiole potassium at late season. Here one can distinguish between soil levels considered deficient and sufficient. In the soils where exchangeable potassium level was less than 100 ppm, plant potassium was generally in the deficient range—less than 4% at late season. Between 100 and 150 ppm the scattered points indicated uncertain yield response to potassium fertilization. Above 150 ppm potassium, yield response would be unlikely.

A GUIDE FOR 7 VEGETABLE SPECIES

Although research with other vegetables has not provided the amount of facts that potato work has, some good facts on critical nutrient levels has been secured for many of them. Table I is a guide for (1) the major nutrient deficiency levels, (2) plant parts, and (3) sampling time for use in plant testing of 7 vegetable species.

Two points to remember are these:

1 The time of sampling suggested is the most appropriate single time for assessing all three major nutrients. Although only one time is given here, two or more samplings on different dates should be made to determine reliably a given crop's nutrient status.

2 As with potatoes, on certain crops it is best to sample early for determining nitrogen and phosphorus needs.

Plant analyses have one distinct disadvantage in vegetable production. Since most vegetables mature rapidly, there is a minimum length of time during which samples can be taken for assessing their nutrient levels.

For example, potatoes, which take approximately 110 days from planting to harvest, require about 60 of those days to produce adequate foliage to sample with any degree of precision. Lettuce, which may grow for only 90 days, does not produce sufficient foliage for sampling sooner than 45 days after planting.

This means that analyses can best be used for adjusting a fertilizer program in future years, since deficiencies can only occasionally be detected early enough to permit additional fertilizer during the sampling year.

THE END

(Grade yourself on vegetables—p. 56)

New Full Color Fact Sheet

Shows Potash Hunger on Corn and on Soybeans

See Page 5

By R. E. Blaser of VPI Who Says . . .

"The K content of alfalfa should be between 2.0 to 2.5% to attain maximum yields. A productive 4-ton alfalfa hay crop will remove more than 200 lbs. of K_2O per acre."

"The P content of productive alfalfa should be 0.26% of the dry weight or higher. A minimum of 50 to 60 lbs. of P_2O_5 should be applied annually to maintain high alfalfa production."

YIELD & UPTAKE

(of P_2O_5 & K_2O)

IN ALFALFA FERTILIZATION

SOIL fertility is the foundation of any successful forage production program.

But other cultural factors that help maximize yields and quality must be considered at the same time.

In fact, the problem of how much and which fertilizer nutrients to apply for perennial forages depends on (1) *Yield responses,* (2) *stand and survival of plants,* (3) *nutrient uptake by plants and removal by cropping,* (4) *build-up or depletion of soils.*

We have used data from alfalfa or alfalfa-grass mixtures grown on three soils to discuss P_2O_5 and K_2O fertilization here.

Phosphorous Fertilization

An alfalfa-orchardgrass mixture was fertilized with different amounts of P_2O_5 on two soils low in available phosphorus in Virginia. The soils were limed to near pH 7, while boron and potash were applied in adequate and constant amounts for all P_2O_5 rates.

1 *On Lodi Soil*

Yield—Figure 1 shows how the alfalfa-grass mixture on the Lodi soil (mountain region) was stimulated with the 50 and 100 lb. P_2O_5 rates. With more than 50 lbs. P_2O_5, yield response was small and diminished as more phosphorus was applied.

Yield: An alfalfa-orchardgrass mixture with P_2O_5 fertilization during the 8th year of production.

PHOSPHORUS

Uptake: Phosphorus content of alfalfa & orchardgrass and total P_2O_5 removed by the crop increased as more P_2O_5 was applied.

The alfalfa in the mixture produced 75% more with 50 lbs. P_2O_5 than without phosphorus. More than 50 lbs. P_2O_5 did not give additional alfalfa growth.

Uptake—phosphorus uptake by alfalfa increased as more P_2O_5 was applied. The P content of alfalfa without P_2O_5 fertilization was 0.2% compared to 0.37% with 200 lbs. P_2O_5—an increase of 89% in P uptake. The difference in hay yield for those two treatments was only 30%. Absorption of P, higher than 0.26%, was not associated with additional alfalfa growth. Orchardgrass absorbed more P than alfalfa at all P_2O_5 rates above the no application level.

Phosphorus absorption was not associated with orchardgrass yields. Since orchardgrass depended on a nitrogen supply from alfalfa, low nitrogen limited grass growth more than phosphorus. The competition from alfalfa also reduced orchardgrass yields.

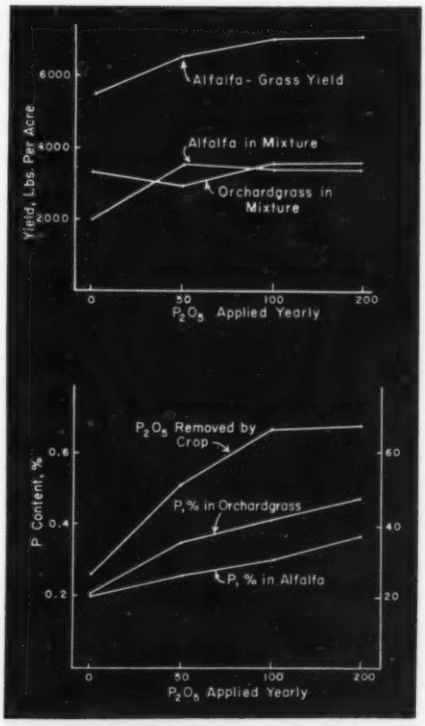


Figure 1—Phosphorus on Lodi Loamy Soil near Blacksburg.

2 *On Cecil Soil*

Yield—Figure 2 shows how an alfalfa-grass mixture on Cecil fine sandy loam in Virginia's Piedmont region was stimulated by annual 50 lb. applications of P_2O_5. In fact, P_2O_5 fer-

tilization gave an 83% increase of alfalfa, but neither the yield of alfalfa nor the alfalfa-grass mixture responded to more than 50 lbs. P_2O_5.

Uptake—Low, consistent increases in phosphorus uptake were recorded for the 50 and 100 lb. P_2O_5 rates. Without P_2O_5, P content of alfalfa averaged 0.19%—with 50 lbs. P_2O_5, the P content was 0.26% P. Without P_2O_5, both alfalfa and orchardgrass P content was similar, but orchardgrass absorbed much more P than alfalfa at all P_2O_5 rates.

3 *On Dickson Soil*

Yield—Figure 3 shows what happened to alfalfa grown on a high-phosphorus Dickson soil in Tennessee, when the lime, K_2O, and boron treatments were similar for each P_2O_5 rate.

During the 4-year study, 60 lbs. of P_2O_5 applied annually increased yields 13%—or better than 0.5 tons per year—over the no-P_2O_5 alfalfa. The higher rates of P_2O_5 did not stimulate higher alfalfa yields.

Uptake—Phosphorus absorption by alfalfa increased with yearly increases in P_2O_5. With 60 lbs. of P_2O_5, the P uptake increased 33%, alfalfa yields 11% over the no P_2O_5 treatment. Although the annual 180 lb. rate of P_2O_5 increased P uptake by 53%, yield increase was only 10% over no P_2O_5.

P_2O_5 Summary

These three long time experiments on three different soils show that alfalfa growth was stimulated by annual fertilization of P_2O_5 at 50 to 60 lbs. per acre. Alfalfa yields increased as P uptake increased to about 0.26% of the dry weight. When alfalfa was 0.2% P or lower, it was in the *phosphorus hunger zone*, too low for rapid growth. Although alfalfa plants were as high as 0.37% P with liberal P_2O_5 fertilization, such high P contents were not accompanied by increased yields.

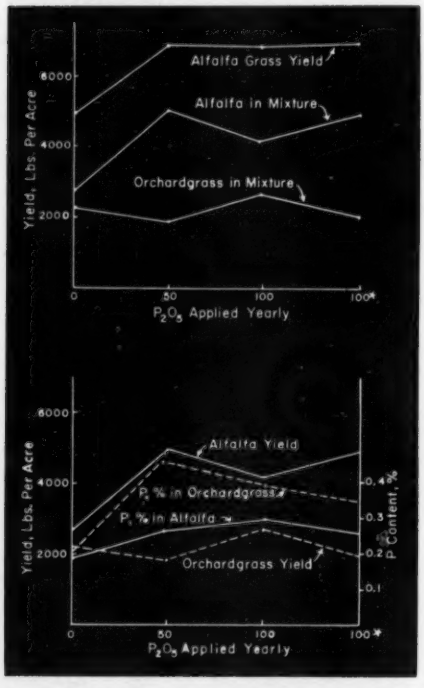


Figure 2—Phosphorus on Cecil Fine Sandy Loam.

Yield: The yield of alfalfa-orchardgrass mixture was improved as the alfalfa in the mixture increased from annual P_2O_5.

PHOSPHORUS

Uptake: The relation between yields and uptake was not good for either alfalfa or orchardgrass. P_2O_5 fertilization increased P uptake of orchardgrass more than for alfalfa.

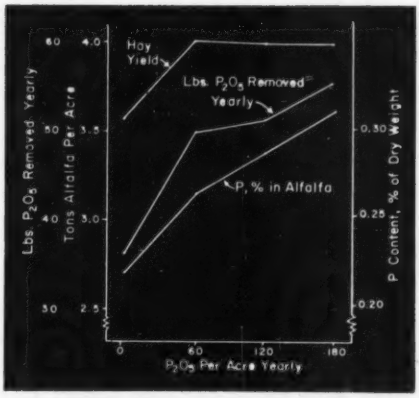

Hay Yield
Lbs. P_2O_5 Removed Yearly
P, % in Alfalfa
Lbs. P_2O_5 Removed Yearly
Tons Alfalfa Per Acre
P Content, % of Dry Weight
P_2O_5 Per Acre Yearly

Figure 3—Phosphorus on a Dickson Soil in Tennessee.

PHOSPHORUS

Showing yields, uptake, and average removal.

Potash Fertilization

The influence of potash fertilization was studied at the same time on the three soils mentioned for the P_2O_5 experiments.

In the Virginia experiments, the soils medium in available potash were limed to about pH 7 with boron and phosphorus applied in liberal and uniform amounts each year at the different K_2O rates. We used an alfalfa-orchardgrass mixture and applied K_2O each spring.

Yields are given for the seventh or eighth productive seasons because the crop was not chemically analyzed each year. In each experiment, yields given are very similar for the average of all years.

Yield: Yearly K_2O fertilization increased alfalfa-grass mixture yields. The yields rose as production of alfalfa in the mixture improved.

POTASSIUM

Uptake: Alfalfa yield rose as potassium content in the hay increased, after more than 100 lbs. of K_2O yearly.

1 *On Cecil Soil*

Yield—Figure 4 shows how the yield of the mixture and the alfalfa fraction increased with more K_2O on Cecil fine sandy loam. The 400-lb. K_2O treatment resulted in 2½ tons more hay than the no-K_2O treatment.

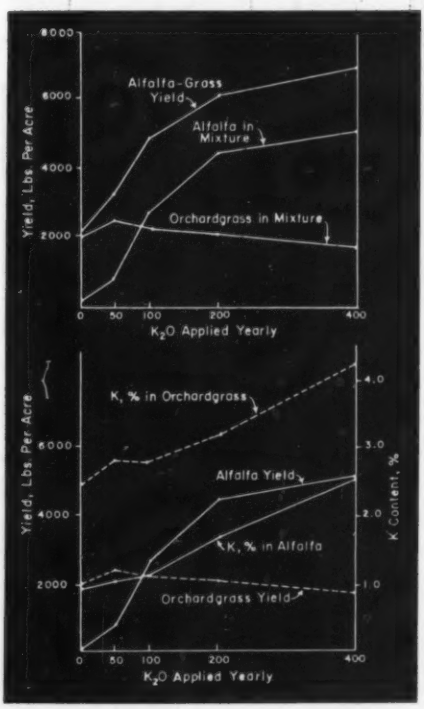


Figure 4—Potassium on Cecil Fine Sandy Loam in 7th Productive Year.

The 200 lb. K_2O rate produced 4,590 lbs. more dry hay than the no-K_2O—or 6,620 lbs. compared to 2,030 lbs. The higher hay yields from increased K_2O are attributed to the stimulated growth and stand of alfalfa.

Orchardgrass in the mixture declined slightly as more K_2O was added. Although orchardgrass has high K_2O requirements, its declining growth with added K_2O was caused by alfalfa aggressiveness with liberal K_2O.

Uptake—Potassium uptake and yields of alfalfa *increased together* when more than 100 lbs. of K_2O was applied. *Below 100 lbs. K_2O per acre, there simply wasn't enough potash to grow and maintain alfalfa.* Orchardgrass absorbed much more potassium than alfalfa, at all K_2O rates. There was no relationship between potassium absorption and yield of orchardgrass. High grass yields are not expected to correlate with fertility when the objective is alfalfa maintenance.

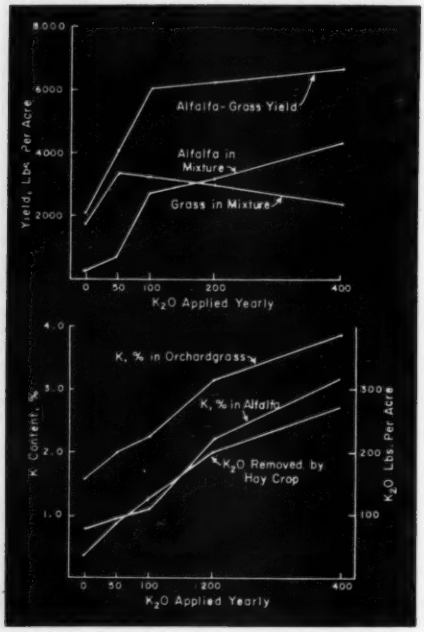


Figure 5—Potassium on Lodi Loamy Soil in 8th Productive Year.

2 On Lodi Soil

Yield—Figure 5 shows how an alfalfa-grass mixture and alfalfa in the mixture increased as K_2O rates increased. The higher K_2O rates did not stimulate mixture growth as much as the 100 lb. rate. For example, the mixture yield increased 112% from the 50 lbs. K_2O treatment, 215% from 100 lbs., 225% from 200 lbs., and 248% from 400 lbs. K_2O. The added K_2O increased the alfalfa fraction even more than the total yield.

Uptake—Potassium uptake of alfalfa increased with added K_2O. At the 0 and 50 lb. K_2O rates, when K uptake was only 0.7 and 1.0%, the alfalfa stand was lost during the first two seasons. At the near optimum rate of 200 lbs. K_2O annually, the K content was 2.0%.

Note how orchardgrass again absorbed more K than alfalfa at all levels of K_2O fertilization. Although orchardgrass yield and K uptake both increased at the 50 lb. K_2O rate, the

Yield: Note how yield of alfalfa-orchard-grass mixture increased as K_2O application rates increased.

POTASSIUM

Uptake: Note how potassium content of alfalfa increased as its yield increased. Potassium content of orchardgrass increased up to 50 lbs. K_2O applied, but showed no relationship at higher levels. Yearly K_2O removal rose as potassium fertilization and yields were increased.

continued K uptake was not accompanied by increased yields as more K_2O was applied.

3. *On Dickson Soil*

Yield—Figure 6 shows what happened to alfalfa grown on low-potassium Dickson soil in Tennessee. During the 4-year study, yields increased from 2.5 tons to 4.27 tons of hay per acre from the following annual applications of K_2O: 2.5 tons hay from no K_2O, 3.56 tons from 100 lbs., 4.00 tons from 200 lbs., 4.25 tons from 300 lbs., and 4.27 tons from 400 lbs. K_2O. The potassium absorbed by alfalfa generally increased as yield increased—from 1.67% content at no K_2O, 1.87% at 100 lbs., 2.87% at 200 lbs., 2.21% at 300 lbs., and 2.49% at 400 lbs. K_2O.

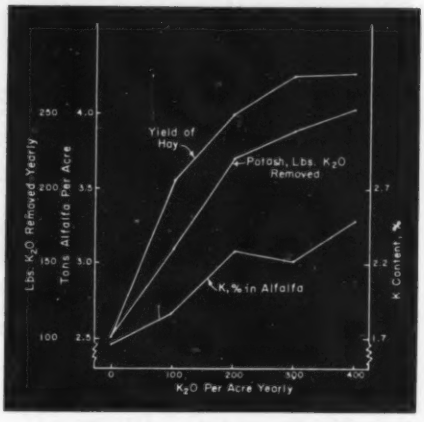


Figure 6—Potassium on a Dickson Soil in Tennessee.

POTASSIUM

Showing alfalfa yield, potassium content, and potash removal with rates of K_2O—as averages per year for a 4-year period.

K_2O Summary

The data from the Tennessee and Lodi soil experiments indicate that the minimum percentage of K for optimum alfalfa growth should be 2.0 to 2.2% or higher. The data from the Cecil soil indicate that the minimum percentage of potassium should be 1.65 or higher.

The lower K uptake by alfalfa on the Cecil soil is due to the sampling method, since the first crop was not saved for K analysis. The K in the first alfalfa crop during spring is usually much higher than for the later crops. The spring crop of alfalfa is especially high in potassium because of late winter or early spring K_2O fertilization and higher availability of soil potash due to winter "weathering" and resting of the colloids.

K_2O Removal and Build-up or Depletion in Soils

The initial soil potassium on a Dickson soil in Tennessee was 159 lbs., low according to soil tests.

Figure 7 shows how much K_2O per acre alfalfa removed yearly under 5 different K_2O treatments on the Dickson soil. With the no-potash or 100-lb. K_2O treatment, there was only 85 to 94 lbs. of available K_2O left in the soil after 4 years of cropping. The soil was depleted of about 45% of the initial available potassium.

Even with 200 lbs. K_2O fertilization, more K_2O was removed than added to the soil. *Soil potash was not depleted when 300 and 400 lbs. of K_2O was added yearly.*

Soil tests indicated the Cecil and Lodi soils in Virginia were medium in available potash.

Figure 8 shows how much K_2O per acre the alfalfa-grass mixture re-

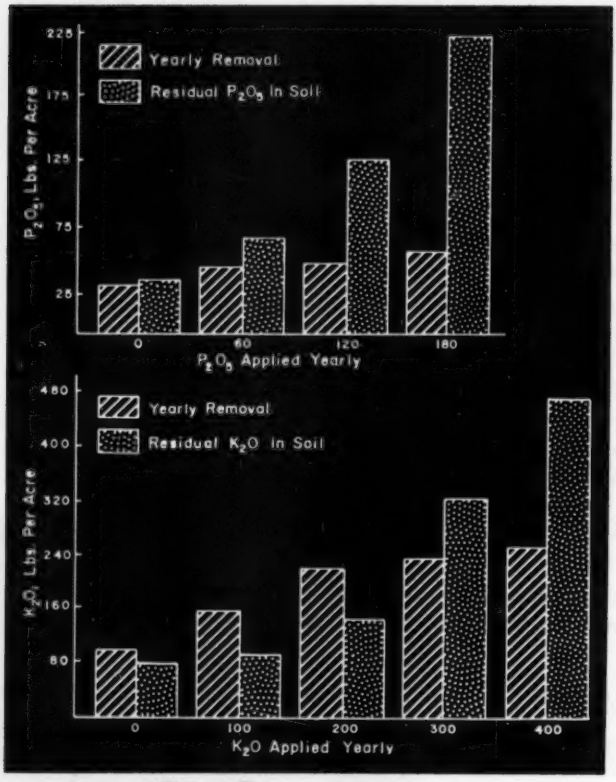


Figure 7

moved under 5 different K_2O treatments on the Cecil soil. Soil potassium was reduced and depleted with less than 200 lbs. of K_2O yearly. The lack of soil build-up with 200 lbs. K_2O and the high soil potash with 400 lbs. K_2O fertilization shows that annual K_2O applications should be more than 200 lbs. per acre, but less than 400 lbs. on similar soils.

Another look at Figure 5 will show how much K_2O the hay crop removed in one year from the Lodi soil under 5 different K_2O treatments. Here the soil tests also showed the soil depleted of available potash when 200 lbs. of K_2O or less was applied yearly.

All of which indicates this:

1 *A productive alfalfa crop or an alfalfa-grass mixture should be fertilized with 200 lbs. of K_2O or more each year.*

2 *The K content of alfalfa should be between 2.0 to 2.5% to attain maximum yields.*

3 *Applying less than 200 lbs. K_2O yearly on soils similar to those discussed will deplete the soil of available potassium.*

4 *A productive 4-ton alfalfa hay crop will remove more than 200 lbs. of K_2O per acre per year.*

P_2O_5 Removal and Build-up or Depletion in Soils

Figure 8 shows how much P_2O_5 an alfalfa-grass hay crop removed each year under 3 different treatments on a Cecil soil. When this experiment

ON ALFALFA-ORCHARDGRASS:

K_2O

Showing results of P_2O_5 and K_2O applied yearly and their removal during a cropping year for an alfalfa-orchardgrass mixture grown on Cecil Fine Sandy Loam. Residual data obtained at end of 7 years of harvesting.

P_2O_5

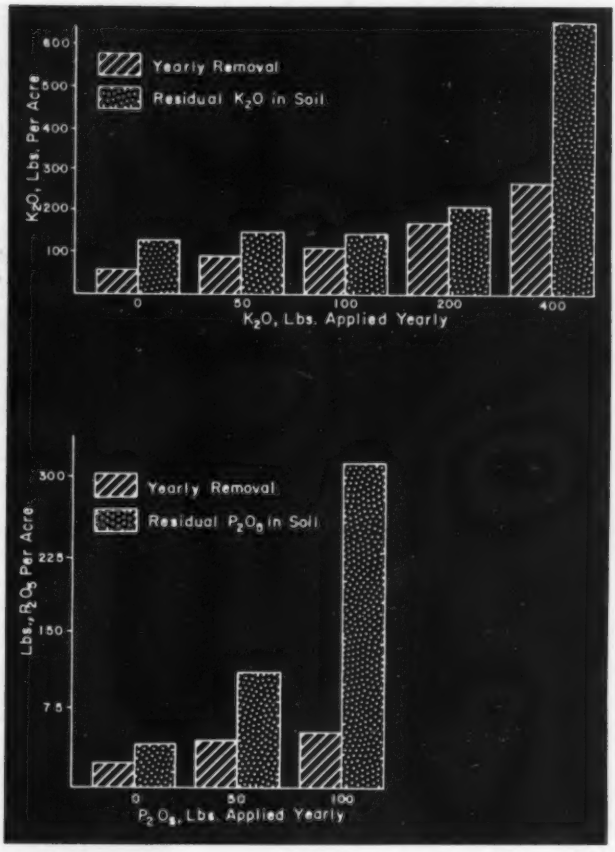


Figure 8

started the soil was low in phosphorus, soil tests showed, but a soil build-up occurred after P_2O_5 had been applied yearly for 9 years. At the end of the 9-year experiment, tests showed 43 lbs. soil P_2O_5 per acre for the no-P_2O_5 treatment area, 114 lbs. P_2O_5 for the 50-lb. treatment, and 316 lbs. P_2O_5 for the 100-lb. treatment.

Some of the build-up of soil phosphorus with the 50 and 100 lb. P_2O_5 rates is attributed to *two* initial annual applications before a crop was harvested. The first spring seeding failed because of diseases, so there was a second seeding and P_2O_5 application before crop harvesting.

The annual P_2O_5 removal by the alfalfa crop on the Lodi soil, Figure 1, which was also low in soil phosphorus when the experiment was started, resembled the Cecil soil experience. Although data are not included here, phosphorus accumulated in the soil as 50 lbs. and more P_2O_5 were applied yearly.

The efficient P_2O_5 absorption and utilization on these two low phosphorus soils in Virginia are partially due to (1) Liming to a high soil pH when the experiments were started and (2) the fact that grass is higher in P than alfalfa.

Figure 7 shows how much P_2O_5

per acre alfalfa removed yearly under 4 different treatments on a Dickson soil high in residual phosphorus.

The 60 lb. rate of P_2O_5 maintained the available soil phosphorus at a high level. The soil phosphorus declined without P_2O_5 fertilization and there was a high build-up when P_2O_5 was applied at 120 or 180 lb. rates yearly.

All of which indicates this:

1 *Phosphorus does not leach, so it is a good practice to use it liberally in seedbeds to get good seedling growth and stands of grasses and legumes.*

2 *A minimum of 50 to 60 lbs. of P_2O_5 should be applied annually to maintain high alfalfa production.*

3 *Such rates of P_2O_5 exceed crop removal and will maintain or build-up soil phosphorus on soils similar to those studied.*

4 *The P content of productive alfalfa should be 0.26% of the dry weight or higher.*

Applying about 750 lbs. of an 0-9-27 or similar fertilizer yearly for alfalfa or alfalfa-grass mixtures, on soils similar to the ones discussed, is necessary to maintain high yields of alfalfa.

With such good fertilization and management, the alfalfa produced about 4 tons of hay per acre (12% moisture) in the 7- and 8-year-old stands.

THE END

For Extra Copies

of this

Special Issue

See Back Cover

GRADE YOURSELF
(on forage)

When alfalfa plants show 0.2% P or lower, they are in the phosphorus hunger zone, too low for rapid growth.

True ☐ False ☐

Below 100 lbs. K_2O per acre there wasn't enough potash to grow and maintain alfalfa.

True ☐ False ☐

As more K_2O was added to the orchardgrass-alfalfa mixture, the grass growth declined slightly because its K_2O requirements are very low.

True ☐ False ☐

The minimum percentage of K content for maximum alfalfa growth doesn't have to be over 1.0 to 1.5%.

True ☐ False ☐

Since phosphorus leaches, it would be wasted if used in seedbeds to try to get a good strong seedling start for later stands of grasses and legumes.

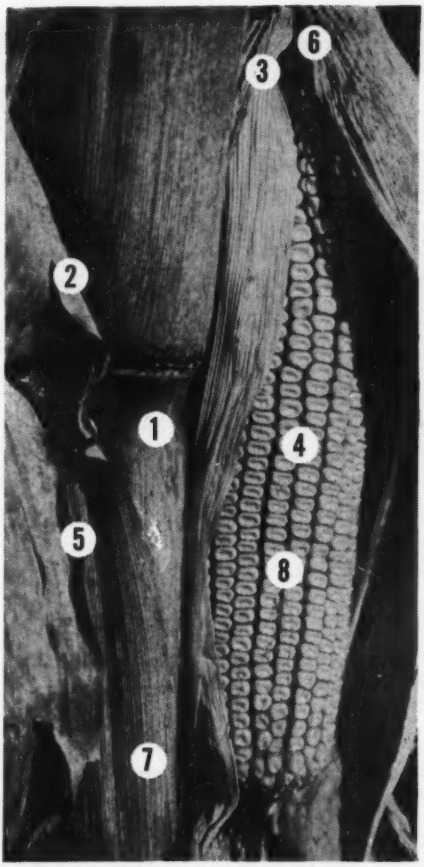
True ☐ False ☐

A productive alfalfa crop or an alfalfa-grass mixture should be fertilized with at least 200 lbs. K_2O or more per acre each year.

True ☐ False ☐

To maintain high alfalfa production, you should apply a minimum of 50 to 60 lbs. P_2O_5 per acre each year on your stand.

True ☐ False ☐



8 BIG REASONS WHY A LOT MORE FARMERS ARE PLANTING *ALL* FUNK'S-G* THIS SPRING

Last year will be remembered as a great corn year—but we'll also remember it as a great test of hybrid performance. Leaf blight, high winds, heavy fall rains, and other hazards put hybrids through their paces as never before in many areas. When have we had so much corn left unpicked until spring?

Corn growing conditions at their best—and worst—as in 1961 prove the remarkable balance and capacity of Funk's G-Hybrids. G-Hybrids paid off for the nation's farmers in 1961 in 8 specific ways—

MORE CAPACITY TO PRODUCE

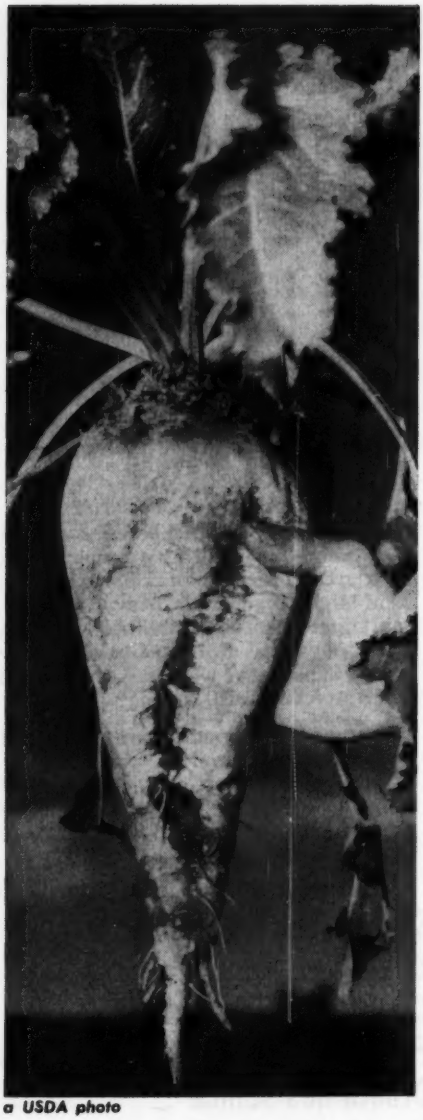
FUNK'S G HYBRID®

1 Strong Standing Stalks
2 Blight Resistance
3 Corn that Holds its Ears
4 Feedability
5 Drouth Resistance
6 Bred for the Newest Harvesting Equipment
7 Effective Use of Soil Fertility
8 Big Yields of Grain or Silage

Result—a lot more farmers are planting *all* Funk's-G in 1962.

*Funk's G-Hybrid is the registered trademark of Funk Bros. Seed Co., Bloomington, Illinois.

THE PRODUCERS OF FUNK'S G-HYBRIDS



a USDA photo

PLANT ANALYSIS

By
Albert Ulrich
University
of
California

"LET the sugar beet plant tell its story"—that's the new way to keep in touch with the fertilizer needs of the sugar beet crop under field conditions.

Such a story starts with the collection of appropriate plant samples, followed by the analytical methods for use in plant analysis and ending with the interpretation of the results for field fertilizer recommendations. The primary ingredients for success are: (1) Securing specific information for individual fields and (2) interpreting this information on the basis of fundamental greenhouse studies and appropriate field plot experimentation.

In brief, the success of any plant analysis program rests with the people involved—the analytical chemist, the agronomist, and the grower—much as in modern medicine, success depends on the clinical technician, the doctor, and the patient.

A sound plant analysis program is not a "one shot" affair. It is a well planned, organized effort geared to learning and meeting the needs of each crop in a way that will maximize net returns to the grower. Plant nutrient inventories are taken yearly to appraise current season's fertilizer practices and to plan the fertilizer programs of succeeding crops.

In the latter instance, the plant analyzes the soil and gives an integrated value of the supplying power of the soil in terms of climate and growth needs of the crop. In this way potential deficiencies are anticipated and corrected long before serious crop losses in yield and quality occur.

The *critical nutrient concentration* is the key point in evaluating the

TABLE 1—A PLANT ANALYSIS GUIDE TO DEFICIENT AND NON-DEFICIENT SUGAR BEET PLANTS[a]

Nutrient	Plant part	Constituent determined	Critical concentration[b]	Range showing deficiency symptoms	Range without deficiency symptoms[c]
Calcium	Petiole	Ca	—[e]	0.04–0.10%	0.2–2.50%
Chlorine	Petiole	Cl	0.4%	0.01–0.04%	0.8–8.5%
Magnesium	Petiole	Mg	—[e]	0.010–0.030%	0.10–0.70%
	Blade	Mg	—[e]	0.025–0.050%	0.10–2.50%
Manganese	Blade	Mn	—[e]	4–20ppm	90–360 ppm
Molybdenum	Blade	Mo	—[e]	0.01–0.15 ppm	0.20–20.0 ppm
Nitrogen	Petiole	NO_3—N	1,000 ppm	0	350–35,000 ppm
Phosphorus	Petiole	H_2PO_4—P	750 ppm	150–400 ppm	750–4,000 ppm
	Blade	H_2PO_4—P	—[e]	250–700 ppm	1,000–8,000 ppm
Potassium (Na more than 1.5%)	Petiole	K	1.0%	0.2–0.6%	1.0–11.0%
	Blade	K	1.0%	0.3–0.6%	1.0–6.0%
Potassium (Na less than 1.5%)	Petiole[d]	K	—[d]	0.5–2.0%	2.5–9.0%
	Blade	K	1.0%	0.4–0.5%	1.0–6.0%
Sodium	Petiole	Na	—[e]	—[f]	0.02–9.0%
	Blade	Na	—[e]	—[f]	0.02–3.7%
Sulfur	Blade	SO_4=—S	250 ppm	50–200 ppm	500–14,000 ppm
Zinc	Blade	Zn	9 ppm	2–13 ppm	10–80 ppm

[a] Leaf material for chemical analysis must be collected shortly after the appearance of the leaf symptoms. If this precaution is not taken, deficient plants may accumulate nutrients within the leaf without restoring "dead" or "chlorotic" tissues to a "normal" condition.

[b] The critical concentration is that nutrient concentration where plant growth begins to decrease in comparison with plants above the critical concentration.

[c] The upper value reported is the highest value observed to date for "normal" plants.

[d] Because of the influence of sodium on the potassium content of the petioles, use the blades for potassium analysis when the petioles contain less than 1.5% sodium.

[e] Not yet determined.

[f] No definite symptoms observed.

. . . GUIDE TO SUGAR BEET NEEDS

nutrient status of a crop as it grows in the field from day to day. Plants above the critical nutrient concentration are adequately supplied with nutrients at sampling time, while those below the critical concentration are deficient and could grow faster with additional supplies of the deficient nutrient.

The longer a plant is deficient in a nutrient, the greater the response possible, if no other nutrient becomes limiting after the first deficiency has been corrected.

The primary function of a complete plant analysis program is to determine what nutrients are deficient, if any, and for how long. Early season deficiencies may be more important than late season deficiencies, and deficiencies lasting many weeks are far more detrimental than deficiencies lasting only a few days.

When you know what plant nutri-

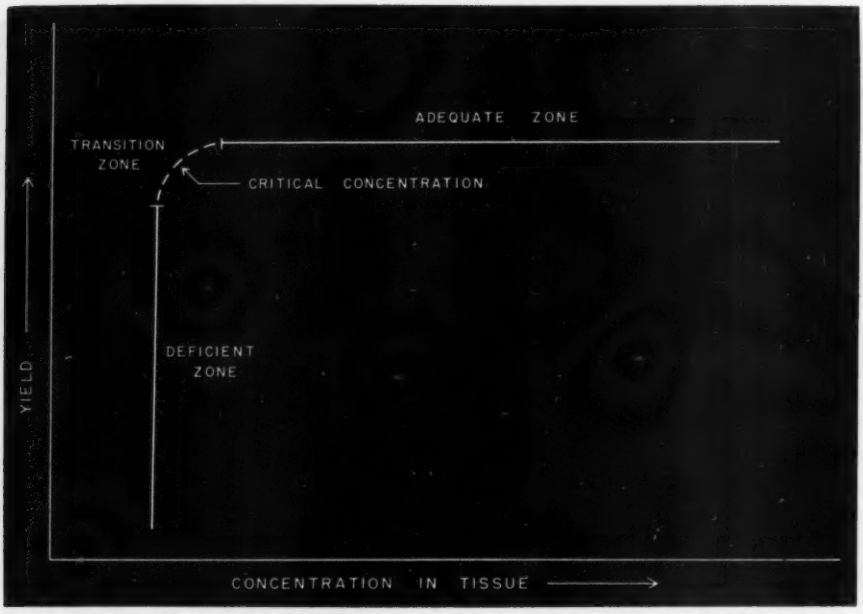


Figure 1—This schematic diagram of a plant nutrient calibration curve relates plant growth (yield) to nutrient concentrations of specific plant parts at a definite physiological age, e.g., petioles or blades of "recently matured" leaves. The critical nutrient concentration is the point where growth begins to be retarded in comparison to plants well above the concentration. Plants continuously above the critical nutrient concentration will not respond to fertilization, while the deficient ones below will respond to fertilization.

ent is deficient and when the deficiency occurs, you can adjust the fertilizer program either in the current crop or in the following crop or in the planning of new experiments in field plot research studies.

Estimating Critical Concentration

The critical concentration of a plant nutrient in relation to growth can be estimated most easily through controlled nutrition experiments. Solutions are prepared with all required nutrients present except the one under study. The latter is added progressively in increasing amounts to the basal medium at the beginning of the experiment, and thereafter the solutions are not changed or renewed except for the addition of salts of the basal medium and water as needed.

The plants receiving the smallest amount of the nutrient controlling growth become deficient first. Others become deficient later, and still others not at all. When the plants in the lower third or half of the series become deficient, all plants are harvested.

Ordinarily a plant nutrient series involves 8 to 10 treatments, five replications per treatment, three plants per pot, and from three to six plant parts for chemical analysis.

For sugar beets the parts usually selected for analysis are the petioles and blades of old, mature, and young leaves. Of these the mature blades and petioles have been found to be the most useful indicator of the nutritional

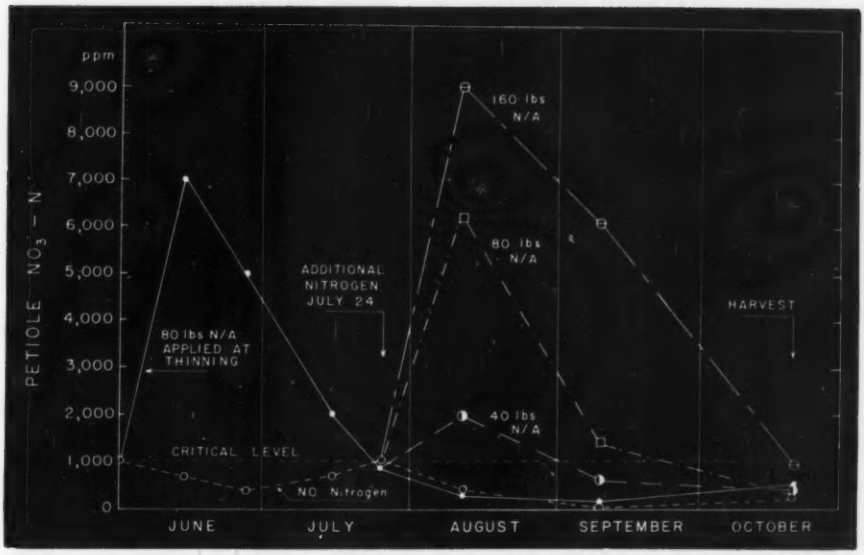


Figure 2—Here are the effects of nitrogen fertilization on the nitrate-nitrogen content (dry basis) of sugar beet petioles, Davis, California. The first petiole samples were taken on May 31, four days after fertilization but before water had been applied to the beets. The second set of petiole samples was taken after the beets had been irrigated.

status of sugar beet plants under field and laboratory conditions. All chemical analyses are made on the dried material ground to pass a 40 mesh sieve.

Figure 1 gives a schematic diagram of a typical calibration curve. Figure 2 shows the application of this knowledge to the fertilization of sugar beets with nitrogen under field conditions. And Table 1 reports the yields and quality of beets harvested.

Plant Analysis Programs

So far, plant analysis programs have been found useful in (1) plant nutrient surveys, (2) field plot experimentation, (3) controlled feeding, (4) evaluating fertilizer programs, (5) fertilizing succeeding crops, (6) scheduling harvests, (7) diagnosing nutrient deficiency symptoms and assessing causal relationships in beet root quality studies.

1 *Plant nutrient surveys*

A systematic survey of sugar beet fields in beet growing areas is very useful in determining the nutrient status of the crop in relation to the fertilizer programs of beet growers, the nutrient supply of the soil, and the nutrient demands made by the crop during the growing season. Through such a survey, problem fields can be discovered and test plots established to correct nutrient deficiencies wherever they occur.

In a plant nutrient survey, one plant sample consisting of 30 to 40 petioles of recently matured leaves is usually taken across the center of each quarter of a field. A maximum of ten acres per quarter is included in a sample and a total of four samples is taken per 40-acre field. Samples are usually taken at thinning, or shortly thereafter, another at midseason, and a final one

TABLE 2—HARVEST RESULTS, DAVIS, CALIFORNIA

Lbs. of nitrogen (N), phosphorus (P_2O_5) or potassium (K_2O) per acre		Tons beets per acre	Per cent sugar	Lbs. sugar per acre
First application May 27 a	Second application July 24	Harvest October 20		
0	0	21.1	15.9	6,680
80N	0	23.6	15.5	7,280
80N	40N	25.9	15.1	7,820
80N	80N	28.5	14.7	8,400
80N	160N	30.4	14.0	8,480
$200P_2O_5$, 80N	160N	29.7	13.6	8,060
$200P_2O_5$, $200K_2O$, 80N	160N	28.4	14.1	8,020
Significant difference		(19:1) 2.3	0.7	1,000
		(99:1) 3.1	0.9	1,340

a Applied shortly after thinning.

at or shortly before harvest. In areas with long growing seasons, two or more mid-season samples may be necessary. Samples are taken every three to five weeks for best results.

When just a single set of samples is taken, the results apply only to the time of taking that sample—whether at thinning or mid-season or harvest. Such surveys are important in finding areas of early season phosphorus responses or for quality studies at harvest. In quality studies, the best correlations between plant analysis and quality are obtained when the petioles and/or blades of recently matured leaves are taken from the same plants as those used for sucrose analysis and for top and root size measurements.

2 *Field plot experimentation*

Once problem areas have been located from the plant nutrient survey, the fields suitable for demonstration trials or for experimentation are selected for further study.

With suitable foresight the fields selected for study can serve many practical purposes: (1) Help train farm advisors or county agents in the applications and interpretations of plant analysis results, (2) extend information about plant analysis programs to growers, (3) evaluate materials and methods of fertilizer application, including timing and rates of fertilization.

Merely adding fertilizers to the soil does not guarantee that the plants absorbed the nutrients applied or that the applied nutrients met the needs of the crop for best growth. Answers to these questions can be obtained by analyzing plant samples taken systematically during the growing season of the crop to final harvest.

3 *"Controlled feeding"*

The plan of "controlled feeding" of sugar beet crops is a good one in areas where fertilization is a new cultural practice or where fields differ widely in soil fertility.

A "wait-and-see" approach applies no fertilizer or only a small amount at first and no more until the results of plant analysis indicate a need for it. This approach is very useful for nitrogen where early deficiencies can be corrected quickly and late applications are to be avoided.

Figure 2 and Table 2 show the results of this approach. Here no nitrogen was applied at planting, and by the time the plants were large enough

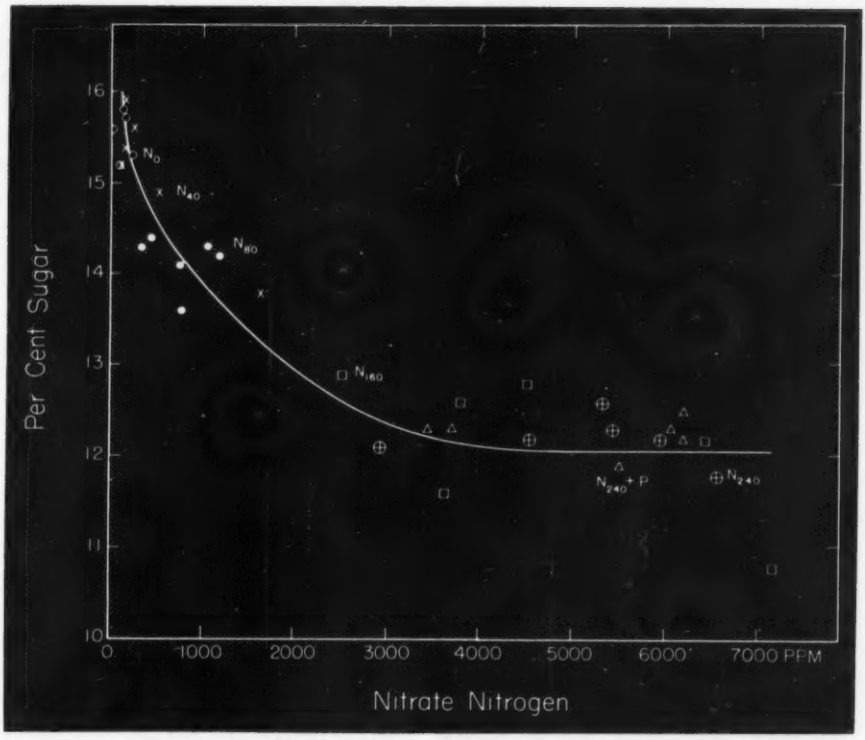


Figure 3—This shows the relation of sugar content of beet roots (fresh basis) to petiole nitrate-nitrogen (dry basis) for sugar beet plants from a field experiment near Woodland, California. The subscripts indicate the pounds of nitrogen applied as ammonium nitrate and the letter P is equivalent to 200 P_2O_5 per acre from treble superphosphate.

to sample, the petiole nitrate-nitrogen values were already at the critical level. Eighty pounds of nitrogen as ammonium nitrate was applied as a side dressing to all but the untreated plots and irrigated shortly thereafter. The fertilized plants increased greatly in nitrate-nitrogen and by July 24 were deficient again.

At this time a second application of ammonium nitrate was made at rates of 40, 80 and 160 lbs. of nitrogen per acre. The petiole nitrate-nitrogen values reflected these applications of nitrogen—with the 80 plus 40 lb. treatment running out too soon, the 80 plus 160 lb. treatment being excessive for an October 20 harvest, and the 80 plus 80 lb. treatment about right for maximum sugar yields.

4 *Evaluating fertilizer programs*

Wherever sugar beet growers have developed a fertilizer program, it is important to learn how well their program has met the needs of the crop, not only for nitrogen but for other nutrients as well. This question can be answered easily by taking a series of plant samples as already outlined: One set early at thinning, one or more sets at mid-season, and a final set just prior to harvest.

By comparing the results of each

sampling to previously established critical nutrient levels, you can determine how well the fertilizer program is meeting the needs of the crop for that year. If a deficiency of nitrogen, phosphorus, potassium, sulfur, etc., is discovered early enough in the growing season, emergency fertilizer applications can be made to correct the deficiency. With more experience and consistent use of plant analysis, minor adjustments in the yearly fertilizer program will meet the crop needs. Plant analysis can also determine the effectiveness of any changes in the fertilizer program. Thus, by consistent use of plant analysis, plant nutrient deficiencies are eliminated and avoided long before serious crop losses have occurred.

5 *Fertilizing succeeding crops*

Using plant analysis as a guide for fertilizing succeeding crops needs much more experience before specific directions can be given.

As a rule, if one crop is deficient in a given element, the possibility of the next crop being deficient in the same element is great but not necessarily as great.

For example, alfalfa might readily respond to phosphorus following phosphorus-deficient sugar beets since both crops are deep rooted, but not after phosphorus-deficient lettuce, a shallow rooted crop. But if lettuce follows either phosphorus-deficient alfalfa or sugar beets, the lettuce might almost certainly respond to phosphorus.

Sugar beets following crops fertilized heavily with nitrogen will require less nitrogen, or even no nitrogen fertilization, compared to beets following unfertilized crops.

6 *Plant analysis as a guide to harvest*

Occasionally, the development of a new tool finds unexpected uses, such as the use of plant analysis in planning harvests or in finding causes for differences in sugar beet quality.

In California—where sugar content of beets has been decreasing progressively from 18.1% in 1937 to approximately 15.3% in 1959—the use of plant analysis has helped greatly in solving this low sugar problem.

Figure 3 shows the relationship of petiole nitrate to the sucrose concentration of beet roots under field conditions. As a rule, the greater the number of days of nitrogen deficiency prior to harvest, the higher the sugar concentration of the beet root.

At present, growers often use the same amount of nitrogen on sugar beets as before, and not less as thought necessary at first. They are applying all of the nitrogen early and none of it after mid-season or at the last irrigation as before to keep the crop growing vigorously to harvest. Whenever possible, fields low in nitrogen are now harvested first, and those high in nitrogen are harvested at the last possible moment during the campaign. Recent experiments have also shown that, ordinarily, there is no loss in sugar produced per acre by a pre-harvest deficiency of nitrogen unless the deficiency period greatly exceeds six to eight weeks.

7 *Diagnosing deficiency symptoms*

At times it is necessary to diagnose the cause of leaf symptoms appearing on sugar beet plants. Quite frequently,

the symptoms can be diagnosed as caused by plant diseases or insects. At other times, symptoms due to nutritional deficiencies can be diagnosed readily if they are not complicated by modifying factors.

But even when the symptoms appear clearly defined, the diagnosis should be confirmed by comparing chemical analyses of the affected leaves (petioles and/or blades) with normal leaves. Table 1 is a guide to values for deficient and non-deficient leaves.

SUMMARY

Plant analysis as a guide for fertilizing sugar beets has been developed from a greenhouse and laboratory curiosity to a tool useful in plant nutrient surveys, field plot experimentations, evaluation of fertilizer programs, diagnosis of plant nutrient deficiency symptoms, and planning of harvest schedules.

Systematic sampling of the plants of every crop on a field can help detect nutritional deficiencies in a crop as soon as, or even before, they appear —enabling progressive growers to take corrective steps before serious crop losses have occurred.

THE END

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GRADE YOURSELF
(on beets)

The *mature* blades and petioles are the most useful indicators of the sugar beet's nutritional status, although old and young ones can be used.

True ☐ False ☐

In a plant nutrient survey, samples are usually taken once a year—at thinning—totaling 8 samples of 30 to 40 petioles each per 30-acre field.

True ☐ False ☐

If a deficiency of N, P, or K is discovered early enough in the growing season, emergency fertilizer applications can be made to correct the deficiency.

True ☐ False ☐

The plant analysis tool is of no value in planning harvests or in finding causes for differences in sugar beet quality.

True ☐ False ☐

Even when leaf symptoms appear clearly defined to the eye—as caused by plant diseases, insects, or nutritional hunger—it pays to confirm your diagnosis by comparing chemical analyses of the affected leaves with normal leaves.

True ☐ False ☐

Deficiencies lasting many weeks are not much more detrimental than deficiencies lasting only a few days, since a deficiency is a deficiency.

True ☐ False ☐

USDA photo

PINEAPPLE CROP LOG

By W. G. Sanford

THE pineapple plant is a long-term crop taking 18-24 months for the first crop and approximately 14-16 months for the second or ratoon crop. It is propagated vegetatively by either slips, crowns, or suckers.

In the Hawaiian Islands, a large percentage of the land has been continuously cropped to pineapple for 50 to 60 years. Soil pH has declined because of the selective removal of nutrients by the crop and the use of large amounts of ammonium sulfate. Many areas are now deficient in one or more of the following nutrients: potassium, phosphorus, calcium, magnesium, and zinc. Also, all areas require nitrogen and most areas iron. The iron demand is not from lack of iron in the soil, but from its not being available to the pineapple plant.

Since 1942 we have been able, on the whole, to correct these deficiencies successfully and maintain good yields by using diagnostic techniques developed

at the Pineapple Research Institute in cooperation with member companies starting in 1935.

Concept

Developing good diagnostic techniques is not done by simply running a few fertilizer experiments. The development of the pineapple crop log has depended on knowledge of soil chemistry and physics, of the many botanical fields including anatomy, physiology, biochemistry, and pathology, of such areas as entomology, nematology, and meteorology.

The crop log as originally developed by G. T. Nightingale is concerned with two areas:

1 Those indices involving the actual determination of nutrient deficiencies —including soil analyses, visual deficiency symptoms, and chemical analyses of the plant.

2 Those indices involving the measurement of other limiting factors that may affect directly or indirectly the nutrition of pineapple plants—such factors as growth rates (as an indication of potential limiting factors), pathogens, parasites, moisture status, and weather.

The crop log not only stresses the importance of knowing that deficiency symptoms do exist, but equally important, *why they exist*. For example, leaf analyses may indicate low potassium while soil analyses indicate high available potassium. Obviously the potassium supply is not limited, so the low level in the plant may be the result of a nitrogen deficiency, moisture stress, nematode infestation, fungus disease, and/or some other factor.

—CONCEPT & DEVELOPMENT

Pineapple Research Institute of Hawaii

Nutrient-Deficiency Indices

Indices for soil-potassium, -phosphorus, -magnesium, and -calcium—developed for pineapple by Oscar Magistad and other workers—are reported as being low, medium, and high. These analyses are used to indicate the nutrient reserves in the soil and to predict the need for preplanting fertilizer applications. But they do not necessarily reflect accurately how much of these nutrients are absorbed by the plant. For this reason and because soil analysis for nitrogen has not been successful as a guide to nitrogen fertilization of pineapple, plant indices are also a very important part of the crop log.

The plant indices for nitrogen, potassium, and phosphorus were developed by Gordon T. Nightingale starting in 1935. These indices involve the use of both visual deficiency symptoms—for determining nitrogen needs, for example

—and chemical analyses of plant tissue—for determining potassium needs, for example.

Visual Symptoms for Nitrogen Needs

Since the pineapple plant has a high nitrogen requirement, considerable research has been done to determine a suitable nitrogen index. As a whole, correlation between any nitrogen fraction in the plant and response from nitrogen fertilizer applications has been poor.

Nightingale reasoned correctly that nitrogen utilization (protein synthesis) is a function of the amount of *carbohydrate* available to the plant. The *carbohydrate synthesis* in the plant in turn is primarily a function of *temperature, carbon dioxide supply,* and *sunlight intensity.* Since these factors vary with locations, the nitrogen needs should likewise vary with location.

To develop a good index for the carbohydrate status of the plant, Nightingale selected the most recently fully expanded leaves (termed D-leaves because they are usually the *fourth* whorl of physiologically active leaves from the base of the plant) from field plants grown in different climates.

Table 1 shows the *four* classes of leaves he selected, varying outwardly in leaf color and texture and internally in carbohydrate status. The carbohydrate status can be determined microscopically. A high carbohydrate plant has thick cell walls and a high proportion of mechanical fibers, while its protein nitrogen (analytically determined) is relatively low.

TABLE 1—CHARACTERISTICS OF LEAVES EXHIBITING DIFFERENT COLORS.

No.	Color	Leaf texture	Amount of carbohydrate in relation to protein-nitrogen
0	Yellow	stiff	variable
1	Yellow green	stiff	high
2	Olive-green	intermediate	medium
3	Blackish-green	soft	low

This Table 1 index was chosen for nitrogen needs because leaf color reveals carbohydrate status.

Nitrogen experiments have indicated the most favorable color for pineapple is in the No. 1 and No. 2 color ranges. This is why leaf color is visually estimated as the percentage of leaves that are No. 1 color. Depending on plant age, the balance of remaining leaves are either No. 0 color when the plant is young, or No. 2 and 3 colors when plants are older. If a plant is 100 percent No. 1 color, all the leaves are yellow or yellow-green. If a plant is 50 percent No. 1 color, 50 percent of the leaves are yellow-green and 50 percent green, while a zero percent No. 1 color reading would indicate the leaves are either green or blackish-green. So, the lower percentage the No. 1 color reading is, the greener the plant.

The desired No. 1 color readings for different stages of growth have been determined by conducting many experiments in areas of different climatic conditions.

Table 2 shows how, with the same total amount of nitrogen fertilization, plot F outyielded plot B—indicating it is *much more important to have a plant green at the time of floral differentiation than during early stages of growth.*

TABLE 2—YIELDS AS RELATED TO NO. 1 COLOR READINGS AND NITROGEN APPLICATIONS.

Plots	Prior Nitrogen lb./A	March Nitrogen lb./A	April No. 1 color %	May Nitrogen lb./A	June No. 1 color %	September Nitrogen lb./A	October No. 1 color %	November Nitrogen lb./A	December[1] No. 1 color %	Total Nitrogen lb./A	Fruit weight Tons/A
B	100	60	87	100	42	80	30	0	30	340	25.70
F	100	0	45	60	28	100	30	80	15	340	27.17*

[1] Floral differentiation.
* Significantly different from B at odds of 19:1.

Table 3 shows how three groups of plants were each maintained at a different No. 1 color reading for the first ten months of growth, so that by August these had No. 1 color readings of 31, 39, and 60% respectively. At this point, each group was split and three rates of nitrogen fertilization applied. The yield data, shown in the last column, indicate that maintaining plants at early stages at different No. 1 color readings had no effect on yields. On the other hand, the No. 1 color readings attained near floral differentiation had a great influence on yields.

TABLE 3—THE EFFECT OF DIFFERENT NO. 1 COLOR READINGS DURING EARLY STAGES OF GROWTH (AUGUST 1959) AND AT FLORAL DIFFERENTIATION (DECEMBER 1959) ON PINEAPPLE YIELD. PLANTED OCTOBER 1958.

No. 1 color reading (percent)		Relative plant crop average fruit weight—(percent)	
Aug. 1959 (Early Growth Stages)	Dec. 1959 (Floral Differentiation)	Jul. 1960	
31	23	111	106
	33	105	
	47	102	
39	23	109	106
	34	106	
	54	103	
60	24	109	104
	35	103	
	58	100	
Statistical significance of differences:			
high	high	high	n.s.

Visual Symptoms for Iron and Zinc Needs

Like nitrogen, the indices used for iron and zinc are visual deficiency symptoms. Although visual deficiency symptoms can be related to iron levels in the plant, the range in iron concentration between extreme iron deficiency and no iron deficiency is so narrow that visual symptoms are more sensitive.

Figure 1 shows how sensitive visual iron-deficiency readings are as an index for iron. For zinc, visual symptoms are preferred because zinc analysis of the growing point, which is the most sensitive tissue, requires the destruction of the plant.

Leaf Analyses for Potassium and Phosphorus Needs

The potassium and phosphorus indices developed by Nightingale—and the calcium and magnesium indices now being developed by the author—are all based on leaf analyses.

Fortunately, the selection of tissue to analyze was made much easier by C. P. Sideris and co-workers working earlier on the nomenclature of pineapple leaves and on exhaustive chemical analyses of these leaves.

The tissue selected for these indices is the basal white tissue of the most recently fully expanded leaves (D-leaves). These leaves are also the longest leaves on the plant and can be readily pulled. Basal white tissue has the advantage of a fairly constant moisture content (in vegetative plants, there is usually a variation of only about 1-1.5 in moisture content). For this reason analyses are usually reported on the *fresh weight* basis.

Techniques used for developing the critical levels for these indices have consisted of solution cultures and many field experiments involving rates of these nutrients.

Nitrogen and potassium are usually the two nutrients most likely to limit pineapple yields. But fertilizer applications of these materials as ammonium sulfate, urea, or potassium sulfate, to attain the critical level of either nitrogen or potassium, can induce calcium or magnesium deficiencies. This is why it is important to consider all nutrients as possible limiting factors.

Limiting Factor Indices

In our enthusiasm for plant nutrition and soil fertility, we often forget that limiting factors are usually not mineral nutrients. My colleague in Hawaii, H. F. Clements, feels that soil moisture level is the greatest single factor influencing plant growth and a very important part of crop logging of sugar cane.

Soil moisture is undoubtedly very important, but so are *all* factors that influence plant water and nutrient absorption and utilization, even when soil moisture and fertility are at optimum. Limiting factors in the pineapple crop log are grouped into three major categories: (1) Growth status as an indicator of potential limiting factors, (2) moisture and root health, and (3) meteorological indices.

Growth Status

Growth status influences nutrition in several ways.

1. A young or small plant requires less amounts of nutrients than an older or larger plant.

2. The concentration of nutrients within the plant markedly changes with age. For example, potassium, magnesium, and calcium concentrations usually decrease with increasing age and size while phosphorus concentration tends to increase.

Figure 1—Visual iron-deficiency readings obtained from plants receiving different frequencies of iron sprays.

Plant growth indices also are valuable as a guide in determining whether growth is normal. The two growth indices used in the pineapple crop log are *D-leaf weights* and *estimated plant weights*:

1 For D-leaf weight, ten D-leaves, one from each of ten plants, are pulled at random in the sampling station. The ten leaves are weighed together and the weight divided by ten to obtain the average D-leaf weight in grams. D-leaf weights are closely correlated with actual plant weights over a wide range. (These same leaves are used for chemical analysis and leaf-water deficiency, as described below.)

2 Estimated plant weights are relatively easy to obtain. Depending on how variable plant weight is in a logging station, either three plants or five plants are selected from the population. These are judged at that particular time to be large, medium, and small plants or very large, large, medium, small, and very small plants, respectively. Three to five plants similar to these, *outside* the logging station, are pulled and weighed in pounds. The number of plants in a total of 100 plants in the logging station falling in each weight class is determined and from this a weighted average is obtained.

For example:

Size	Weight—lb.	No. of plants	Total weight—lb.
Very large	5.5	13	71.5
Large	4.7	19	89.3
Medium	3.9	25	97.5
Small	3.1	31	96.1
Very small	2.3	12	27.6
		100	382.0

$$\text{Weighted average plant weight} = \frac{382.0}{100} = 3.82$$

Here, the estimated plant weight for the plot is 3.8 pounds. An experienced logger can by-pass the preliminary step and from long experience give an overall estimation of average plant weight in the logging station.

Moisture and root health

Several indices are available for determining if moisture will be a limiting factor in pineapple growth. Direct measures are soil moisture and rainfall. Indirect methods are leaf-water deficiency readings and counts of the numbers of white root tips, expressed as percentage.

Pineapple leaves have two layers of grossly different tissues: (1) A layer of chlorophyllous or chloroplast-containing cells, (2) a layer of water-storage cells. A four-month-old plant, supplied with sufficient water, shows a ratio of one part water-storage tissue to two parts green tissue. But when moisture is limiting, the proportion of water-storage to green tissue decreases. Thus water deficiency can be read as a percentage of the total possible thickness of water-storage tissue. The percentage of white root tips is obtained by recording the number of roots with white tips (and thus actively absorbing) as a percentage of the total number of root tips.

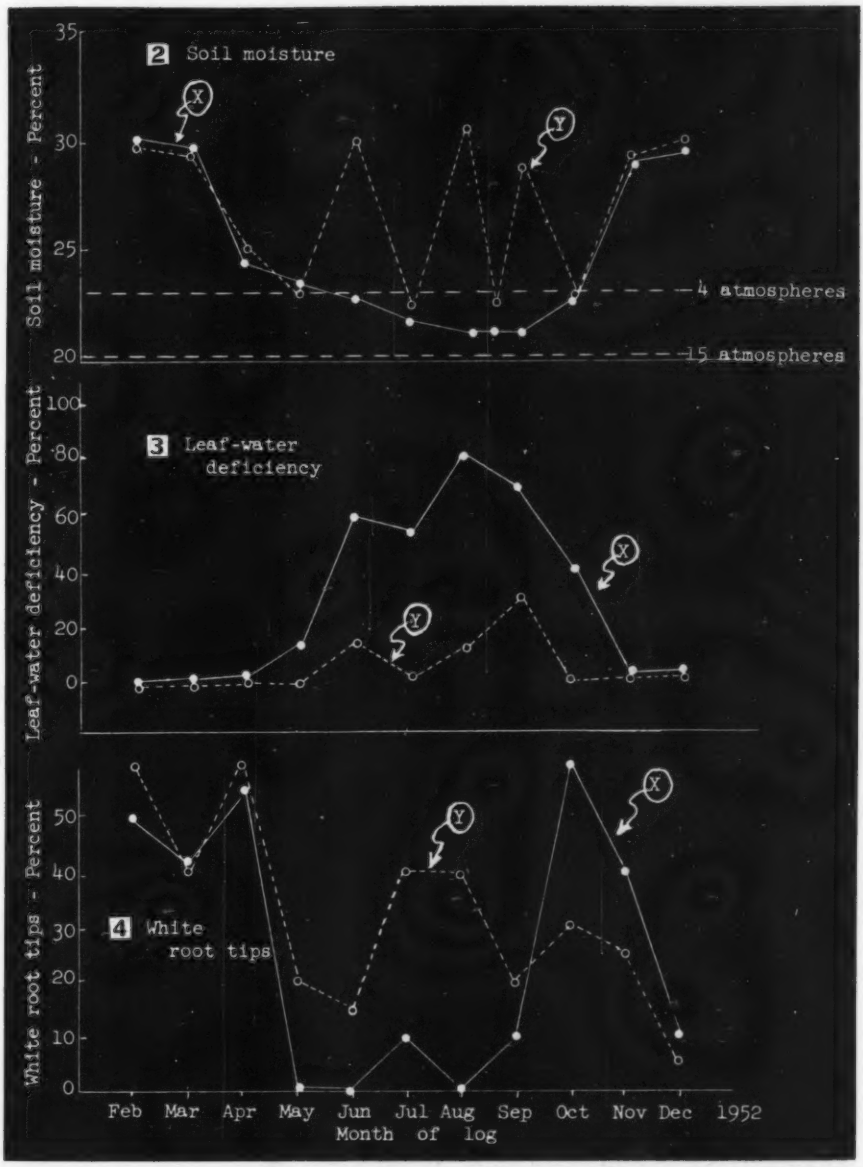
Since nutrients must be in solution to be absorbed by the roots and move within the plant, soil and plant moisture do influence plant nutrition. Figures 2 through 7 illustrate this relationship. These results were obtained from an irrigation experiment where *Treatment Y* was maintained at a soil moisture level above 4 atmospheres by irrigation. They showed this:

In Figure 2, plants in Treatment X received no irrigation, causing soil moisture level in these plots to fall below 4 atmospheres.

In Figures 3 and 4, the differences in soil moisture in the two treatments were clearly reflected in leaf-water deficiency and white root tip readings.

In Figures 5, 6, and 7, the plants receiving more moisture (Treatment Y) had higher leaf-nitrate (5), -phosphorus (6), and -potassium (7) values than those receiving no irrigation (Treatment X).

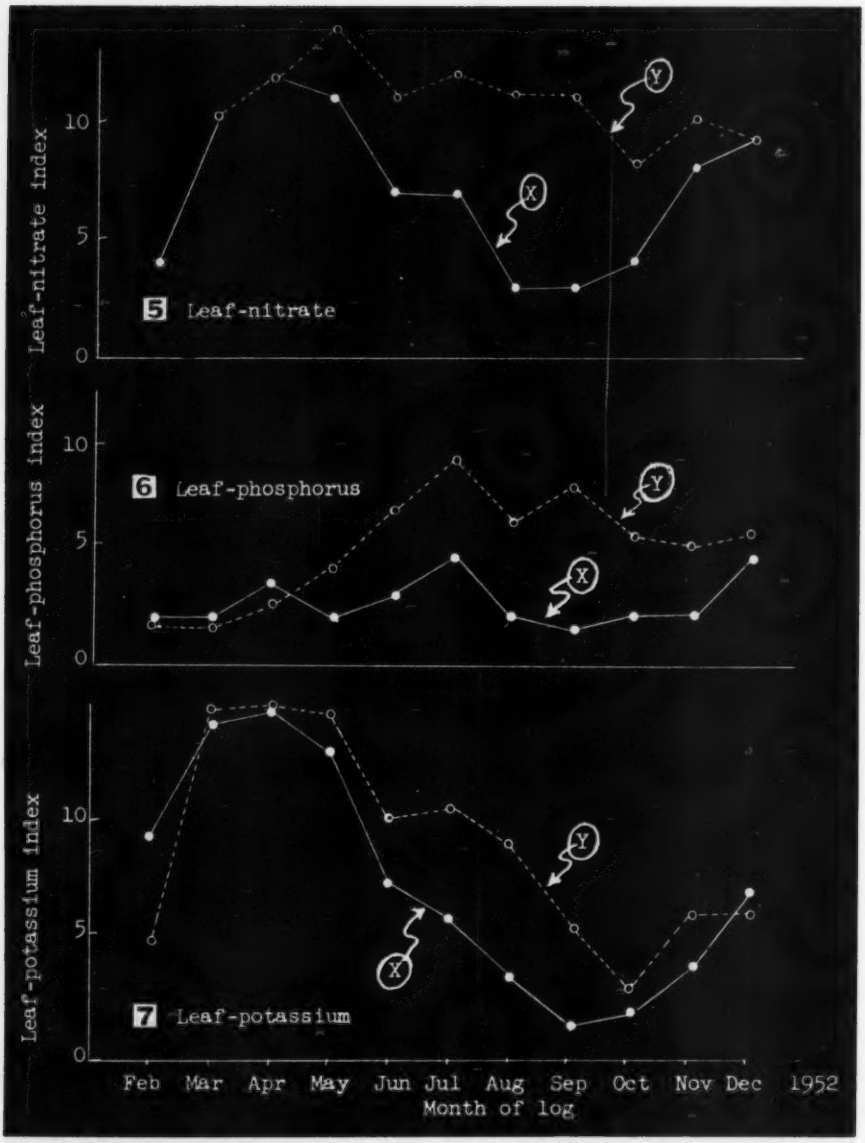
Nematodes, particularly the root knot and reniform species, are very important limiting factors in pineapple production. D-D mixture (1, 3-dichloropropane and 1, 2-dichloropropane) and BBC (1, 2-dibromo-3-chloropropane) were discovered as soil fumigants for nematode control by W. Carter and C. T. Schmidt, both staff members of the Pineapple Research Institute. Since all



FIGURES 2, 3, 4 **Influence of irrigation (Y) and no irrigation (X) on soil moisture (2), leaf-water deficiency (3), white root tips (4).**

pineapple fields in Hawaii are fumigated, much evidence on the effect of nematode control on leaf-nutrient levels has been gathered. For example:

1 Preplanting soil fumigation, particularly with methyl bromide and D-D, increases the availability of ammonium-nitrogen during the early stages of



(See p. 39 legend Figures 2, 3, 4). Influence of irrigation (Y) and no irrigation (X) on leaf-nitrate (5), leaf-phosphorus (6), and leaf-potassium (7).

FIGURES 5, 6, 7

growth by suppressing the nitrifying organisms that convert ammonium-nitrogen to nitrate-nitrogen—but phosphorus uptake is decreased.

2 Fumigation consistently increases plant manganese and halides—to levels in excess of amounts required by plants.

3 Such nematode control permits a better root system and generally increases the potassium, magnesium, calcium, and some micronutrient levels in leaves—while No. 1 color and iron-deficiency readings decrease, indicating increasing leaf levels of nitrogen and iron as well.

In addition to nematodes, important parasites which can be limiting factors are *Anomola* beetles, symphylids, and root-rotting fungi.

Meteorological Factors

Pineapple is grown in Hawaii from just above sea level to as high as 2200 feet. Temperature and net radiation generally decrease with elevation while rainfall increases.

Figure 8 shows the effect of temperature on growth. Here both root and leaf elongation are seriously retarded when temperatures read below 70° or above 95° F.

Low temperatures of themselves reduce nutrient uptake. But when they fall below 70° F, fertilizer on pineapples is of little value since the main factor limiting growth is low temperature.

Although pineapple has a low water requirement, rainfall distribution is such that moisture can become a limiting factor when temperature and radiation are optimum.

Light intensity or total radiation greatly influences pineapple yields, as dis-

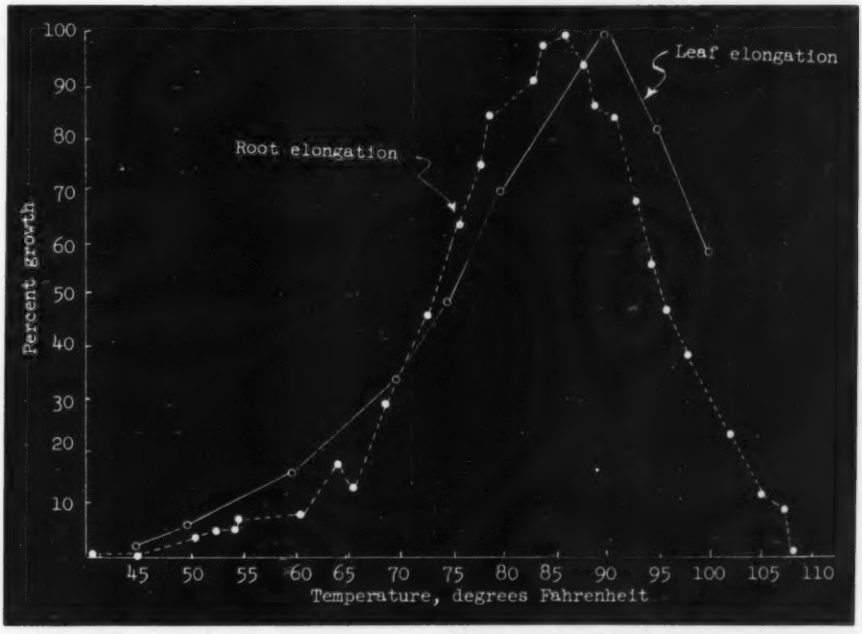


Figure 8—The effect of temperature on root and leaf elongation. Data reported as percent of the maximum. Leaf elongation data obtained by C. A. Farden and root data obtained by S. Watanabe in Japan.

covered by C. P. Sideris et al. For every 20% decrease in radiation, yields decreased about 10%. This was undoubtedly related to carbohydrate synthesis and its effect on nitrogen utilization as previously discussed.

Since temperature, rainfall, and net radiation are extremely important, numerous weather stations are located on plantations.

Sampling Errors

The physical and chemical indices used in the crop log are as subject to errors as soil analyses.

Table 4 shows the coefficients of variability for several of these indices. Not only do these indices vary from each other but within one index there is variation with age. Note leaf-calcium, here representing the *plot-to-plot variability in a relatively small area.* It is easy to imagine how much larger the error may become when one secures a relatively small number of samples in a large field. Similar experiences have occurred in South Africa.

Several factors probably contribute to the variations in physical and chemical indices: (1) Variations in the soil-nutrient levels, (2) size and age of plants, (3) diurnal variations, (4) differences between D-leaves on the same plant, and (5) analytical accuracy, precision and sensitivity. Some of these factors contribute more than others, but altogether they can increase coefficients of variability considerably.

TABLE 4—COEFFICIENT OF VARIABILITY OF CHEMICAL AND PHYSICAL INDICES USED IN THE CROP LOG. DATA FROM ONE EXPERIMENT.

	Coefficient of variability (percent)		
Age in months:	8	12	14
Estimated plant weight—lb.	—	10.2	8.7
D-leaf weight—gm.	6.8	5.9	5.8
No. 1 color—percent	9.3	11.1	13.1
Iron deficiency—percent	—	15.8	13.3
Leaf-phosphorus—percent	5.2	—	—
Leaf-potassium—percent	2.2	10.6	10.1
Leaf-magnesium—percent	3.2	12.8	9.1
Leaf-calcium—percent	5.3	15.3	23.13

Number and Placement of Log Stations

A log station consists of at least 100 plants, one station per 35 acres in uniform fields. Since plant-to-plant variation is greater between beds than within a bed, the station includes at least five beds. Beds adjacent to field roads and plants immediately adjacent to walkways are omitted. Once the station is established, it becomes permanent unless something happens to the plants that is not typical of the balance of the field—such as lack of soil fumigant, root-rot, etc. At that time a new station is established.

Physical logs are taken once a month, starting three to five months after planting, depending on how soon growth commences. If fertilizer applications are made frequently, then chemical logs are made every month. However, if applications are made infrequently, then a chemical log every two months is sufficient.

Soil analyses will give one an excellent idea of how much stress should be placed on each leaf nutrient value. For example, plant analyses for calcium and magnesium are not necessary if the soil pH is above 4.5. However, if high rates of potassium have been applied, calcium or magnesium deficiency may be induced, even though soil levels are relatively high.

Summary

1 The pineapple crop log does not determine exact levels of fertilizer that should be applied. Because of other operations involving labor and equipment, fertilizer applications do have to be scheduled to some extent. The log indicates when one should add or subtract from this schedule.

2 Both soil and plant indices are recommended. They complement each other—the soil analyses indicating the soil reserves, the plant indices indicating how much of this reserve is getting into the plant.

3 Both controllable and non-controllable limiting factors are very important in determining the absorption of nutrients from the soil and applied fertilizer and the utilization of these nutrients within the plant.

4 Because the pineapple plant has a long cycle (3.5 to 5 years) demanding frequent fertilizer applications, we can obtain a continuous monthly quantitative record of plant status (with error reduced by having replication in time). This provides sufficient time to correct nutrient deficiencies when and if they do occur.

5 Log data provide only an estimation of field conditions. But past experience and records of previous cycles help reduce the possibility of any serious error in interpreting log data.

THE END

GRADE YOURSELF
(on pineapple)

Nitrogen and potassium are usually the two nutrients most likely to limit pineapple yields.

True ☐ False ☐

Soil tests may indicate two things: (1) nutrient reserves in the soil, (2) how much of those nutrients the plant absorbs.

True ☐ False ☐

Leaf analyses for potassium, phosphorus, calcium, and magnesium in pineapple plants are usually reported on the *fresh weight basis.*

True ☐ False ☐

Soil and plant moisture have no influence on plant nutrition.

True ☐ False ☐

Nematodes can be very important limiting factors in pineapple production.

True ☐ False ☐

Both root and leaf elongation are seldom affected when temperatures read below 70° F or above 95° F.

True ☐ False ☐

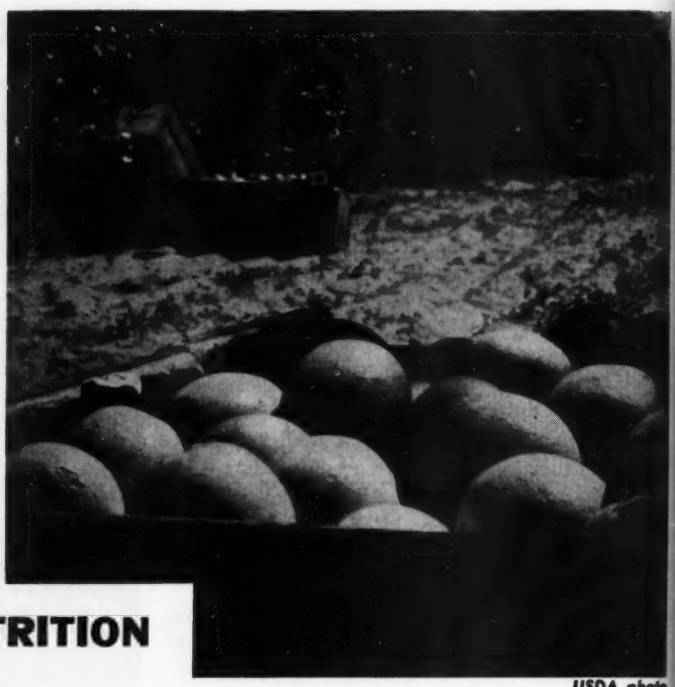
Both *soil* and *plant* tests are recommended—to determine soil reserves and how much of this reserve is getting into the plant.

True ☐ False ☐

Light intensity or total radiation has little, if any, influence on pineapple yields.

True ☐ False ☐

LEAF ANALYSIS AS A GUIDE TO ORANGE NUTRITION



USDA photo

By Walter Reuther

University

FOR several decades, much research has attempted to relate the concentration of nutrients in citrus leaves to nutrient deficiency symptoms or excesses and to yield, vigor, and fruit quality.

Sufficient progress has been made in developing and applying standards to make leaf analysis a very useful tool—not only to investigators concerned with soil fertility problems, but also to technical advisors and growers concerned with practical fertilizer problems.

This article will outline methods for evaluating the nutrient status of orange trees under field conditions by leaf analysis and procedures for arriving at a sound fertilizer program.

Standards

The standards presented in Table I have proved useful in diagnosing the nutrient status of Valencia orange trees. They are based on concentration of nutrient elements in samples of bloom-cycle leaves 5 to 7 months old obtained from non-fruiting terminals. Fruit quality, leaf symptoms, and yield are considered in setting the standards. Quality factors are reviewed elsewhere.

With minor adjustments, the standards in Table I probably can be applied to other important commercial orange varieties. Grapefruit seems to have a lower optimum range for nitrogen. Appropriate adjustments for

TABLE 1—TENTATIVE LEAF ANALYSIS GUIDE TO DEFICIENT AND NON-DEFICIENT VALENCIA ORANGE TREES

Element	Unit (dry matter basis)	Ranges*				
		Deficient	Low	Optimum	High	Excess
N	%	<2.2	2.2 to 2.3	2.4 to 2.6	2.7 to 2.8	>2.8
P	%	<0.09	0.09 to 0.11	0.12 to 0.16	0.17 to 0.29	>0.3
K	%	<0.7	0.7 to 1.1	1.2 to 1.7	1.8 to 2.3	>2.3
Ca	%	<1.6?	1.6 to 2.9	3.0 to 5.5	5.6 to 6.9	>7.0?
Mg	%	<0.16	0.16 to 0.25	0.26 to 0.6	0.7 to 1.1	>1.2?
S	%	<0.14	0.14 to 0.19	0.2 to 0.3	0.4 to 0.5?	>0.6?
B	p.p.m.	<21	21 to 30	31 to 100	101 to 260	>260
Fe	p.p.m.	<36	36 to 59	60 to 120	130 to 200?	>250?
Mn	p.p.m.	<16	16 to 24	25 to 200?	300 to 500?	>1000?
Zn	p.p.m.	<16	16 to 24	25 to 100?	110 to 200?	>300?
Cu	p.p.m.	<3.6	3.6 to 4.9	5 to 16?	17 to 22?	>22
Mo	p.p.m.	<0.06	0.06 to 0.09	0.10 to 0.29?	0.3 to 0.4?	>——?
Cl	%	?	?	<0.3	0.4 to 0.6	>0.7?
Na	%	#	——	<0.16	0.17 to 0.24	>0.25?
Li	p.p.m.	#	——	<1?	2 to 9	>10?

*Based on concentration of elements listed in 5- to 7-month-old, bloom-cycle leaves from nonfruiting terminals. Adapted and revised from Reuther and Smith, and Jones and Embleton.
#These elements are not known to be essential for normal growth of citrus.

W. W. Jones, T. W. Embleton, and C. K. Labanauskas

of California

lemon and mandarin varieties have not yet been fully established. These standards cannot be applied when leaves subtending fruit are sampled. The various oranges shown in Table I indicate the following conditions:

1 Values in the *deficiency range* indicate a deficiency of the element severe enough to cause leaf symptoms or distinct yield and/or quality reduction.

2 Values in the *low range* indicate a supply of the element inadequate to produce maximum yield or best quality under most, but not all, conditions.

3 Values in the *optimum range* indicate an adequate supply of the element for satisfactory tree vigor, productivity, and fruit quality.

4 Values in the *high range* indicate a very abundant soil supply of the element, or some derangement caused by a deficiency of some other element or by a disease of different origin.

5 Values in the *excess range* show leaf symptoms or indicate definite reduction in yield or fruit quality caused by excessive availability of the element in the soil or by a serious derangement in metabolism caused by another nutrient deficiency or other disease.

Growing experience in various parts of the world indicates that these standards have rather broad application in soil and climatic conditions adaptable to citrus. And although they are not infallible, they are useful aids in solving practical problems in commercial citrus production.

Sampling

Careful, standardized sampling procedure by persons trained for the job is essential to successful use of leaf analysis.

Certain factors independent of soil conditions have an influence on leaf composition: (1) Leaf age, (2) whether leaf originates in a bloom flush or later growth cycle, (3) whether leaf originates on a fruit-bearing shoot or not. (See Table II.)

So it is necessary to standardize such growth factors in collecting samples for analysis. For example:

1 Leaves must be from 5 to 7 months old, free of chlorosis, tipburn, insect or disease injury, mechanical damage, etc.

2 They should be from nonfruiting terminals originating from the major bloom flush.

3 Leaf samples must not be from trees obviously damaged by disease, insect or other pests, and physical or chemical injury.

4 Samples obtained for fertility control purposes, and to represent a block of about 5 acres, should consist of 100 leaves obtained from 4 to 5 terminals on each of 20 to 25 trees well distributed throughout the area it is to represent.

5 Samples should be collected in paper bags or other suitable containers and brought to the laboratory the same day as collected, if possible. If held for several days before drying, they should be in cool (not freezing) storage.

6 If only major elements are to be determined, the leaves may be washed in tap water and rinsed in distilled water to remove superficial dust and spray residue. If minor elements are to be determined, usually more elaborate washing procedures are required.

7 The leaves should be dried at 60° C in a forced-draft oven as soon as possible and ground to 40 mesh or finer and stored in tight containers until analyzed.

TABLE II—COMPARISON OF COMPOSITION OF 5-MONTH-OLD VALENCIA ORANGE LEAVES FROM NONFRUITING AND FRUITING TERMINALS

From a Field Experiment Near Pala, California

Method of sampling	Percent of dry weight [1]			
	N	P	K	Mg
From nonfruiting terminals	2.36	0.128	0.86	0.250
From behind young fruits	1.53	0.083	0.38	0.349
Sign.[2]	***	***	***	***

[1] Each value represents the mean of 24 determinations. Paired samples were obtained from each of 24 trees.

[2] *** indicates statistical significance at the 0.1% level.

8 Laboratory assay methods of good accuracy and precision are necessary, while quick test or kit methods of low accuracy or precision are not recommended.

Interpretation

When interpreting leaf analysis remember the balance factor which can displace standards and modify their interpretation. The levels of other elements, as well as other difficulties, can influence interpretation. These problems are discussed in the following look at specific nutrient elements:

1 Nitrogen

Nitrogen has an overriding influence on leaf analysis interpretation. If the level of nitrogen nutrition is not known by actual leaf analysis or previous experience, it is almost pointless to try to classify the status of any other nutrient.

Adequate nitrogen level is basic to satisfactory vigor and productivity.

When nitrogen concentration in leaves is low or deficient, phosphorus, sulfur, boron, and potassium are likely to be higher than normal—and magnesium lower. In this low range, leaves are likely to be slightly yellow, fruit quality satisfactory, but yield poor.

Abnormally high nitrogen concentration in leaves is usually associated with low concentrations of phosphorus, sulfur, potassium, and sometimes one or more of the heavy metals. In this high or excess range, leaves will be dark green, fruit quality may be adversely affected, and other deficiencies not there when the nitrogen level is lower may be present.

2 Phosphorus

The indicated ranges apply only when the nitrogen level in leaves falls in the optimum or lower ranges. If nitrogen is in the high or excess range, then the classification standards tend to be displaced downward.

When phosphorus concentration in the leaves is in the low or deficient range, leaves may be somewhat pale, tree vigor and yield low, and fruit large, coarse textured, and acid, though well colored.

3 Potassium

High potassium concentration in leaves having an optimum nitrogen concentration will usually be accompanied by low magnesium and calcium values and, in some cases, one or more heavy metals may be lowered. In fact, deficiencies of magnesium and of some of the heavy metals may be induced by heavy potassium fertilization.

When potassium is low to deficient (below 1.1), the fruit is almost certain to be small, but yield per acre may not be sharply reduced until potassium level is 0.4% or less.

When potassium is high, fruits are likely to be large, acid, and poorly colored, but total yield may not be adversely affected unless high potassium is preventing adequate uptake of some other element in short supply.

4 Calcium

When leaf calcium is high, the other major bases, the heavy metals, and boron are likely to be low.

High leaf calcium usually indicates a calcareous soil in which availability of these elements is likely to be a problem.

Low leaf calcium usually indicates very acid soil, unfavorable soil structure, unbalanced base nutrition, a toxic effect of some heavy metal, or some combination of several of these factors.

Calcium deficiency has not been reported on field grown trees.

5 Magnesium

When magnesium is low to deficient, chlorosis and abnormal defoliation are mild to severe, but fruit quality usually is not seriously affected until the deficiency is severe.

No benefit has been observed from magnesium in the high range where uptake of potassium and calcium may be depressed.

6 Iron, Copper, Zinc, Manganese, Molybdenum and Boron

When deficient, these elements all tend to derange normal mineral metabolism.

Deficiencies of the heavy metals are typically associated with abnormally high nitrogen and potassium and low calcium in leaves. Most heavy metal deficiencies show distinctive deficiency symptoms on the leaves of some branches even in the low range, and can be fairly readily recognized if complications with other deficiencies do not occur. Unfortunately, complications are the rule rather than the exception. An excess of one heavy metal in the soil can be expected to induce deficiencies of others.

Boron level in the leaves is closely related to available boron in the soil. Both boron deficiency and excess exhibit characteristic leaf symptoms.

7 Soluble salts

High soluble salt concentration in the soil may first reduce tree vigor by restricting the availability of water to the roots.

In high concentrations, soluble salts may also cause specific toxic reactions in the plant.

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As a rule, symptoms such as low vigor, foliage chlorosis and necrosis, and heavy premature loss of leaves are associated with excess soluble salts in the soil—but fruit quality may be good.

When sulfates, chlorides, or sodium in leaves are in the high range, reduced tree vigor should be suspected, even when no clear-cut foliage symptoms can be detected.

When sulfates, chlorides, or sodium are in the excess range, chlorosis, necrosis, and defoliation and poor vigor are usually common symptoms.

Limitations

Conclusions based on leaf analysis alone can lead to faulty diagnosis unless such limiting factors as disease, pest, soil, tilth, and soil drainage are evaluated when leaf samples are taken. Reliable interpretations of the leaf standards presented in Table I presume the root systems of the trees sampled are not restricted or damaged. For example:

1 Poor aeration from poor drainage or soil compaction can reduce the capacity of feeder roots to take up nutrients.

2 Other factors damaging the root system—diseases, nematodes, insect pests, or starvation from girdling or heavy defoliation—may cause apparent deficiencies of those elements in scant, but normally adequate supply.

Such problems do not alter the basic nutrient needs of the tree but are limiting factors which may relate only indirectly to the tree's mineral nutrition.

Leaf analysis can never be a substitute for a wide horticultural knowledge of citrus trees. But it is a useful guide for mineral nutrition needs.

The End

GRADE YOURSELF
(on citrus)

Certain factors independent of soil conditions can influence leaf composition—such as leaf age, whether leaf originates in a bloom flush or later growth cycle, whether leaf originates on a fruit-bearing shoot or not.

True ☐ False ☐

Abnormally high nitrogen concentration in leaves is usually associated with equally high concentrations of phosphorus, potassium, and sulfur.

True ☐ False ☐

Conclusions based on leaf analysis *alone* can lead to faulty diagnosis unless such limiting factors as disease, pests, soil tilth, and soil drainage are evaluated when leaf samples are taken.

True ☐ False ☐

Successful samples consist of 100 leaves from 4 to 5 terminals on each of 20 to 25 trees well distributed over a 5-acre block.

True ☐ False ☐

Sample leaves should be 5 to 7 months old, free of any damage and from non-fruiting terminals originating from the major bloom flush.

True ☐ False ☐

The samples can be collected in paper bags and stored in any convenient place for a few days or weeks until you can take them to the lab.

True ☐ False ☐

PLANT ANALYSIS . .

By J. J. Hanway

LEAF analysis is a valuable tool for diagnosing nutrient deficiencies in corn plants, and it can be made more valuable than it is at the present time.

The value of leaf analyses and the method of analysis used depends on your ability to interpret the results and your use of those results. Leaf analyses are a valuable tool for surveying the nutrient status of plants in areas where little is known about nutrient availability to plants and for evaluating fertilization and other factors influencing the nutrient status of plants in field experiments.

But the use of leaf analyses for advising farmers on fertilizer use for a specific crop in a specific field can present difficult problems. Because of economic considerations in corn production—especially the cost of fertilizer in relation to the price of corn—it is not enough to know whether nutrient levels are adequate for maximum yields. (This is not the case for high value crops where the cost of the fertilizer is low in relation to the price of the crop.)

With corn, the greatest profit comes from applying somewhat less fertilizer than needed for maximum yields. So it is necessary to know the degree of a nutrient deficiency and to be able to predict with reasonable accuracy the yield increases expected from specific amounts of fertilizer. This requires (1)

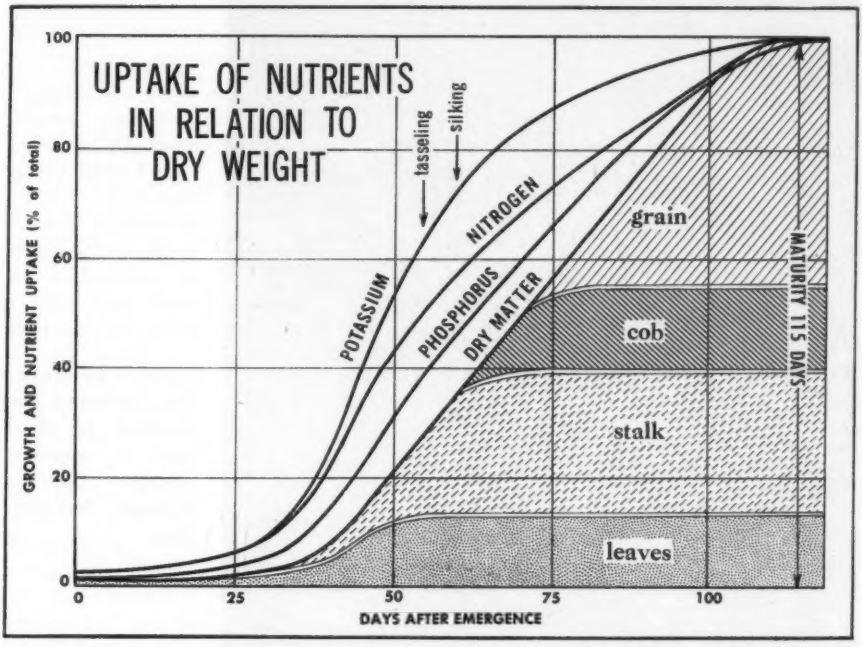

Figure 1—The rate of nutrient uptake and dry matter accumulation is slow early in the season, very rapid later—making amounts of nutrients required early in season very different from later requirements.

S...GUIDE FOR CORN NEEDS

Iowa State University

relatively precise methods of diagnosis and (2) a close eye on all other factors that influence crop response to fertilizer applications.

Several factors can cause the composition of corn leaves to vary: (1) The stage of growth of the plant, (2) certain environmental conditions, (3) the varieties or hybrids, (4) the cultural practices and (5) the different amounts of nutrients available in the soil.

So it is not always a simple job to interpret the results of leaf analyses and predict corrective treatment when nutrient deficiency is indicated.

But the fact that the corn leaf will reflect the nutrient status of the plant makes leaf analysis a unique test for finding nutrient deficiency and proceeding to evaluate the factors that may be causing that deficiency.

Early Sampling

In practice, one would like to analyse corn leaf samples and immediately apply any nutrients needed.

But this is not always possible, because such analyses would have to be

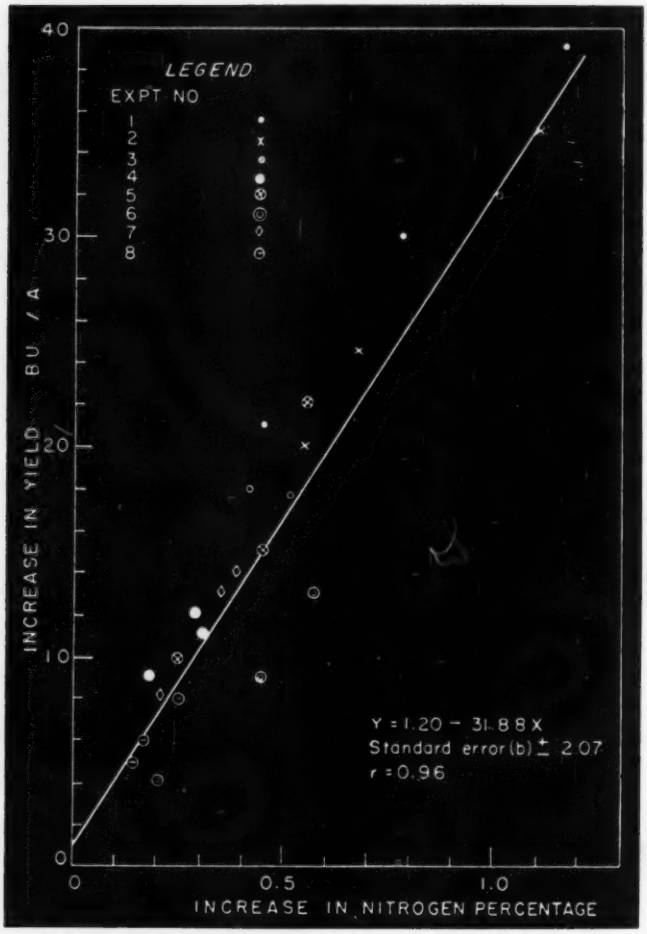

Figure 2—Relation between the increase in yield and in percent nitrogen due to nitrogen fertilization.

made on relatively young plants for fertilizers to be applied while the plants are still small enough to get the machinery over the field without injuring the plants. (On irrigated fields the situation is slightly different because fertilizers might possibly be applied in the irrigation water.)

So far, little research has been conducted with this goal in mind. A number of factors show why:

1 Figure *1* shows how the rate of nutrient uptake and dry matter accumulation is slow early in the season, but becomes very rapid later. Thus, the amounts of nutrients required early in the season are very different from later requirements.

2 Environmental conditions (moisture and temperature) of the early period usually differ from the later period, influencing nutrient uptake during the early stages of growth quite differently from the later stages.

3 Very young corn plants respond more readily than older plants to high nutrient concentrations, making relatively small amounts of "starter" fertilizer near the seed at planting time a common practice. This "starter" fertilizer may supply adequate nutrients during the early growth stage of the

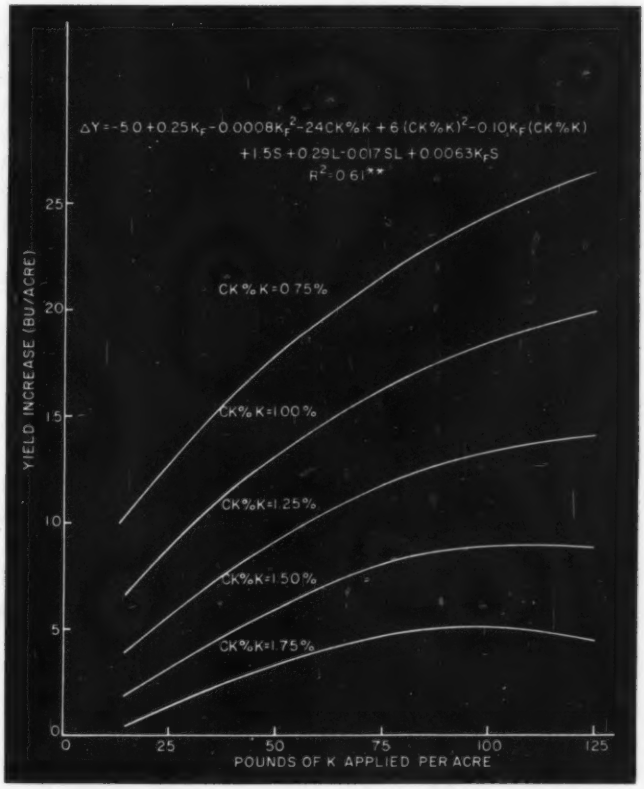

Figure 3—Predicted yield increases of corn grain from K fertilizer applications in relation to the percent K in corn leaves at silking time from plots that received no K fertilizer. (K_F = lbs. of fertilizer K applied per acre, CK%K = % K in leaves of corn plants where no K was applied, L = dry weight of 20 corn leaves = 93.1 grams S = plants per acre = 13,300.)

From: North Central Regional Potassium Studies 111. Field Studies With Corn. North Central Regional Publication No. 135. J. J. Hanway, S. A. Barber, R. H. Bray, A. C. Caldwell, M. Fried, L. T. Kurtz, K. Lawton, J. T. Pesek, K. Pretty, M. Reed, and F. W. Smith.

corn plants but be very inadequate later in the season.

But—even with these factors—the possibilities in analyzing young corn plants should not be forgotten. When young plants can tell you what fertilizer application might correct a nutrient deficiency that season, the results might be very profitable.

Sampling at Silking Time

The most widely accepted method of leaf analysis for corn uses leaf samples collected at silking time.

Although sampling at this stage of growth is too late to permit corrective fertilizer treatments for that crop year, the analyses are useful to research work and to the farmer's future plans.

Sampling at silking time has several advantages:

1 The stage of growth is easily recognized and the position of the leaf to be sampled can be easily described. Most investigators use the leaf opposite and just below the uppermost ear.

2 The rate of nutrient uptake by the plants at this stage is rapid and has been rapid for some time, causing differences in nutrient supply available from the soil and the effects of

other factors to be readily apparent in the composition of the leaves.

3 Good relationships have been obtained between the composition of the leaves at this stage and the yield response from fertilizer applications.

Such leaf analyses are very useful where only one nutrient is deficient. So, let's consider the relationships for the individual fertilizer nutrients.

1 **For Nitrogen**—The N content of corn leaves at silking time usually ranges from 1.0 to 3.5 on an oven-dry basis.

Several investigators have gotten little or no yield increase from N applications where leaves from plants that received no N exceed 3.1% N. But when N content of the corn leaf is below 3.1%, the yield increase is *inversely proportional to the N content of the leaf and proportional to the amount of N applied.* (In some cases, where drouth has limited corn yields, the percent N in the leaf above which no increase in yield was obtained from N applications has been about 2.5 rather than 3.1%.) Also, where other factors are reasonably constant, yield increase from different rates of N was directly proportional to the increase in percent N in the corn leaf resulting from the fertilizer application. One such relationship is shown in Figure 2.

2 **For Phosphorus**—The P content of corn leaves at silking time ranges from about 0.1 to 0.5% on an oven-dry basis.

Little or no yield increases from P applications have occurred where P content exceeds 0.33% in the leaves. Where P in the leaves at silking time is between 0.10 and 0.33%, very satisfactory relationships between P content and yield increase from P applications have been obtained.

3 **For Potassium**—The K content of corn leaves at silking time ranges from 0.5 to greater than 2.0% on an oven-dry basis.

No yield increases have resulted from K applications where leaves contained more than 2.0% K, and yield increases were small where K content exceeded 1.5%. Figure 3 shows the relation between K content of leaves and yield response from K applications. This is the kind of relationship desired if plant analysis is to be used for advising farmers.

But remember: The relationship varies with different plant populations, with methods of fertilizer application, and with other factors—all of which must be considered in any specific situation.

Where more than one nutrient is deficient, the analyses will highlight the *most limiting* nutrient, making it difficult to determine the status of the other nutrients.

For example, N-deficient corn leaves always contain low P percentages. Applications of N to such N-deficient plants may result in an increase—but with no change or even a decrease in the P content of the leaves, depending on the availability of P in the soil. N-deficient corn plants tend to contain high K percentages in the leaves. The decrease in the K content of the leaves resulting from additional N for such plants varies markedly as the level of available K in the soil varies.

Therefore, leaf analysis is useful in determining the status of the most limiting nutrient but cannot be used to predict the availability of the other nutrients when one is limiting.

Quick Field Tests

Another method of evaluating nutrient status in corn plants is the tissue test—using some conductive tissue of

the plant to determine the amount of certain soluble portions of the nutrients in certain plant tissues rather than the total amount in the leaf.

Most of these tests have been developed more on a qualitative or semi-quantitative basis for use as quick tests in the field. Quantitative relationships have not been adequately developed.

However, these quick tests (when conducted and interpreted properly), combined with visual observations of nutrient deficiency symptoms in the field, can provide useful information. Since various factors may markedly influence the concentration of nutrients in the conductive tissues, such tests should be made several times during the growing season.

1 For Nitrogen—A test for nitrate-N is used to evaluate the N status of the plant. Readily detectable amounts of nitrate-N will usually be found in the midribs of the leaves of corn plants when the leaves contain more than 3.0% total N. This test—of nitrate-N in the leaf midrib—will tell whether N is deficient but will not give the degree of deficiency. However, unless N deficiency is very severe, nitrate-N will be found in the stalk of the plant, especially in the lower nodes. Tests for nitrates in these lower nodes does, therefore, provide a method of estimating the degree of N deficiency, but research is needed to make the tests more quantitative.

2 For Phosphorus—Visual deficiency symptoms for P in corn are of little value. So a reliable quick field test for P should be very useful. And since a nearly constant proportion of the total P in a given part of the corn plant is water soluble, tests to determine the amount of soluble P in the corn leaf should provide relationships similar to those for total P in the leaves. However, most current quick tests use some tissue other than the leaf. And although they are useful, considerable research is needed to make them more quantitative.

3 For Potassium—Essentially all K in corn plants is water soluble. So there is no appreciable difference between determinations of soluble and total K in a plant tissue. The amount of K in the conductive tissues varies more and is more sensitive to environmental changes than the K content of the leaf blade. So, testing for K in the conductive tissues has its advantages and disadvantages, depending on the use to be made of the results, when and how often the plants are to be tested, etc.

Factors to Consider

When using plant analyses as a research tool or as a recommendation tool for a farmer's succeeding crops, you might remember these points:

1 Be sure your plant sampling accurately represents the plot or field, since different areas can exist within a single plot.

2 Be sure to consider the many factors—such as stage of growth, environmental conditions, etc.—that affect plant composition and response.

3 Soil tests teamed with leaf analyses can give a more reliable prediction of the factor or factors causing a nutrient deficiency in the plants and a better basis for recommending a correction.

4 Soil tests can also tell you what nutrients other than the one found limiting by plant analysis will be uncorrected when the most limiting nutrient is corrected.

Using leaf analysis at silking time, together with reliable soil tests, should provide a more reliable basis for advising farmers in the future. **The End**

GRADE YOURSELF
(on corn)

The most widely accepted leaf analysis method for corn uses leaf samples collected at silking time—the leaf opposite and just below the uppermost ear.

True ☐ False ☐

Nutrient uptake and dry matter accumulated by corn is very rapid in early season but very slow later on.

True ☐ False ☐

Starter fertilizer may supply adequate nutrients during early corn growth but may be very inadequate later in the season.

True ☐ False ☐

Several investigators have gotten major yield increases from N, P, or K applications where N content of the leaf exceeded 3.1% or P content exceeded 0.33% or K content exceeded 2.0%.

True ☐ False ☐

Where more than one nutrient is deficient, the analysis will highlight the most limiting nutrient, making it difficult to determine the status of other nutrients.

True ☐ False ☐

Your plant sampling should accurately represent the plot or field, since different areas can exist within a single plot.

True ☐ False ☐

GRADE YOURSELF
(on vegetables)

Individual samples consist of 40 to 50 petiole sections of the 4th leaf below the growing tip of the potato plant, generally the youngest fully expanded leaf on the plant.

True ☐ False ☐

Under field conditions, nitrogen in potato plant petioles is generally low during early growth but increases to high concentration by maturity—regardless of N applied.

True ☐ False ☐

Since potassium concentrations in potato petioles can run high during early growth even on relatively low-K soils, samples should be taken no earlier than midseason.

True ☐ False ☐

Many California soils frequently cropped to potatoes are becoming depleted of available potassium.

True ☐ False ☐

Since most vegetables mature slowly, there is plenty of time to take samples and adjust the fertilizer program on the current crop.

True ☐ False ☐

Potato plants grown in deficient and adequately fertilized soils show greatest N and P composition differences during *early growth*—and greatest K differences in the *later sampling period*.

True ☐ False ☐

Top-dressing alfalfa with borated fertilizer pays for itself—better than 3 times over! In Wisconsin alone, averages for 316 alfalfa demonstrations (with borates added to the mix) harvested from 1955 through 1959, gave these dramatic results:

Treatment	Fertilizer Acre Rate	Acre Yield Dry Matter	Increase Per Acre	Increased Value	Fertilizer Cost Per Acre	Net Profit Per Acre
Top-dressed with 0-10-30B	480 lbs.	8368 lbs.	2970 lbs.	$37.12	$8.50	$28.62
Not top-dressed		5398 lbs.				

Source: Mimeo report, C.J. Chapman, Soils Dept., University of Wisconsin

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